Senior Honors Thesis

Monte-Carlo Simulation of Traveltime-Related Capture Zones of Advective Contaminant Migration to Wells

by

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ABSTRACT

Aquifer tests performed at the North Canton, Ohio wellfields indicated that the mean hydraulic conductivity of the Massillon Sandstone aquifer is 49 ft/d. The Massillon Sandstone is approximately 90 ft thick in this region and is overlain by about a 45 ft thick shale unit that acts as a leaky confining layer. The Hantush-Jacob model (equation) was used as a conceptual model for representing the flow system at the North Canton wellfields based on time versus drawdown plots of the aquifer test data.

The deterministic best-estimate values of the hydraulic properties computed from the aquifer test data are a hydraulic conductivity of 49 ft/d, a transmissivity of 4,460 ft^2/d, a storativity of 0.00005, and a vertical hydraulic conductivity of the confining layer of 0.012 ft/d. The best-estimate porosity value of 25 percent is within the range of values cited for sandstone (0.14 to 0.49) given by Mercer and others (1982).

In the stochastic approach the hydraulic parameters used to characterize the Massillon Sandstone were obtained by generating independent random values of hydraulic conductivity and porosity through the use of the International Mathematical and Statistical Library (IMSL) computer subroutines. The normal random values were converted to represent the data describing the Massillon sandstone aquifer based on the best-estimate values of hydraulic conductivity equal to 49 ft/d and porosity equal to 25 percent. One hundred independently generated random values of hydraulic conductivity and porosity were ordered to induce a correlation in pairs.

A semianalytical flow model based on the Hantush-Jacob equation was used to calculate predicted drawdowns under pumping conditions at intersections of a rectangular grid superimposed on the study area. The predicted head distributions were used in a particle-tracking analysis to compute flowpaths and traveltime-related capture areas using the best-estimate hydraulic parameters and 50 sets of hydraulic parameters from the Monte-Carlo data for each of the three bedrock wells under study.

Comparison of the capture-zone area for each well based on the best-estimate values with the most probable area based on the Monte-Carlo method showed that the best-estimate area for NC-1 was 23 acres and the most probable area range was 23 to 25 acres. The area for NC-2 using best-estimate values was 50 acres, whereas the most probable area using the Monte-Carlo data was between 50 and 54 acres. The best-estimate area for NC-1 was 135 acres, and the Monte-Carlo data predicted two

INTRODUCTION

The 1986 amendments to the Federal Safe Drinking Water Act initiated a nationwide program to help protect municipal ground-water supplies from contamination. The Wellhead Protection Program requires delineation and management of areas surrounding municipal water-supply wells. Within these designated areas land-use restrictions are to be enacted by local zoning boards to discourage commercial, industrial, or municipal land uses that may have deleterious effects on public water resources. The United States Environmental Protection Agency (U.S. EPA) has defined the term "wellhead protection area" as, "the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are likely to move toward and reach such water well or wellfield (U.S. EPA, 1987)." One type of wellhead protection area, as described by U.S. EPA (1987), is a traveltime-related capture zone. A traveltime-related capture zone is the surface projection of the area surrounding a well through which water moves along flowpaths toward the well in a given time period.

Governor Celeste requested the Ohio EPA to include an ordinance similar to the federal Wellhead Protection Program in the Safe Drinking Water Bill presented to the Ohio General Assembly in April 1990. Ohio, as well as several other states, has elected to delineate some wellhead protection areas based on traveltime-related criteria; in particular, the area surrounding a well that encompasses a ground-water traveltime to the well of 1 year and 2 years. The outline of these capture zones will help municipalities locate monitoring wells to be routinely sampled to determine whether contaminants are migrating toward the wellfield. If any contaminants are detected in these monitoring wells the additional 1-year traveltime to the water-supply wells will enable the municipality to initiate necessary remedial measures. Delineation of the capture zones requires use of site-specific values of hydraulic parameters such as permeability, water-level gradients, and porosity, as well as a knowledge of the local geologic setting, well capacities, and pumping schemes.

There are approximately 1,600 community water supplies in Ohio. Twelve hundred of these supplies are obtained from ground-water sources and together produce about 500 million gallons of water per day. Most of this production is from buried-valley aquifers. Under the proposed bill, each of the 1,200 municipal ground-water suppliers would be responsible for delineating the 1-year and 2-year capture zones surrounding their wells. The quality of some of these ground-water sources already has been ruined by contamination. Nearly 12 percent of the 1,200 municipal ground-water supplies in Ohio have been polluted, (Dan Leavell, Ohio EPA, personal communication, 1990).

Purpose and Scope

U.S. EPA has recommended six methods to delineate wellhead protection areas. These methods range from use of a circle of fixed radius, to use of sophisticated numerical ground-water flow and solute-transport computer programs. The recommended scientific methods are all based on best-estimate values of hydraulic parameters and do not address the natural variations in parameter values in geologic materials.

The specific objectives of this project are to delineate traveltime-related capture zones for the three municipal bedrock wells operated by the City of North Canton, Ohio, using a deterministic approach based on best-estimate values of hydraulic parameters. These capture zones will be compared to the set of capture zones computed using a Monte-Carlo stochastic approach. The Monte-Carlo approach is based on random sampling of statistical distributions of the hydraulic parameters that attempts to assess the uncertainty inherent in the best-estimate values.

Location of Study Area

The study area surrounds the municipal wellfields of the City of North Canton in Stark County, Ohio (Figure 1). The study area covers portions of northeastern Jackson Township and northwestern Plain Township of the Canton Quadrangle in Stark County. North Canton operates three wellfields containing five wells located in an industrial park in a north

Figure 1. Topographic map of study area showing the location of North Canton City wells.

to south trending valley which parallels Interstate I-77. The principle high-yielding wells, which are the focus of this study, are the three wells penetrating the bedrock aquifer referred to as NC-1, NC-2, and NC-4 (Figure 1). NC-1 and NC-2 are located in the more northern Freedom Avenue Wellfield, whereas NC-4 is located in the Glenwood Avenue Wellfield located 1.5 miles southeast of the Freedom Avenue Wellfield. The other two municipal wells, NC-3 and NC-5, are completed to shallower depths in the unconfined glacial-drift aquifer. NC-3 and NC-5 are located directly south of the Freedom Avenue Wellfield in the Dressler Road Wellfield. NC-1 is contaminated with trichloroethylene (a solvent/degreaser) and is no longer used. Together the other four wells produce about 3.2 million gallons per day and serve nearly 6,000 users. (Analysis of the capture zones for the wells completed in the glacial-drift aquifer is not in the scope of this project.)

Hydraulic Parameters

The parameters needed to characterize the leaky-confined bedrock aquifer under study are hydraulic head, hydraulic gradient, effective porosity, lateral hydraulic conductivity of the aquifer, and the vertical hydraulic conductivity of the confining layer. Hydraulic head, as defined by U.S. EPA (1987, p. C-11), is

> "the height above a datum plane (such as mean sea level) of the column of water that can be supported by the hydraulic pressure at a given point in a ground-water system. It is equal to the distance between the water level in a well and the datum plane."

Hydraulic gradient, as defined by Fetter (1988, p. 571), is the change in hydraulic head with a change in distance in the direction that yields a maximum rate of decrease in head. Hydraulic head and hydraulic gradient are presented in this report in the units of feet.

Effective porosity is the ratio of the total volume of voids available for fluid transmission to the total volume of the porous medium. Effective porosity is symbolized as n.

Fetter (1988, p.571), defines hydraulic conductivity as, a coefficient of proportionality describing the rate at which water can move through a permeable medium. Lateral hydraulic conductivity is symbolized by K and has units of feet per day (ft/d). Hydraulic conductivity is dependent on porosity. It is also necessary to determine the vertical hydraulic conductivity of the confining layer that overlies the bedrock aquifer. Vertical hydraulic conductivity, K', is a measure of the rate at which water migrates vertically through a permeable medium under a unit hydraulic-head gradient and also has units of ft/d.

Technical Approach

The aquifer parameters previously described are all subject to natural geologic variations and, therefore, uncertainty due to the heterogeneous character of most geologic materials such as an aquifer. Values of Hydraulic parameters vary laterally and vertically across relatively short distances in heterogeneous formations. These variations affect the size and shape of traveltime-related capture zones. As a result, they also affect the areas subject to regulation of existing and future land use. The technical approach employed in this study uses two different scientific methods to address the uncertainties in the values of hydraulic parameters: a deterministic approach and a stochastic approach.

The deterministic part of the study conforms to one of the recommended capture-zone delineation methods suggested by U.S. EPA. This deterministic approach does not directly address the inherent uncertainties associated with the best-estimate values of hydraulic parameters. Rather, the best-estimate values are assumed to represent an average of the variations in hydraulic properties within the study area. The direct effects of these uncertainties on capture-zone characteristics will be assessed using a stochastic approach. The type of statistical method used is the Monte-Carlo method. Monte-Carlo simulation entails using a random sampling of statistical distributions of two of the hydraulic parameters (hydraulic conductivity and porosity), performing repeated simulations (trials), and computing multiple capture zones for each of the three North Canton bedrock wells. Characteristics of the capture zones such as variations in shape, area, and position are compiled and then evaluated to assess their probability of occurrence relative to the randomly-generated parameter values. Although the data used in the Monte-Carlo approach are a set of randomly-generated values hydraulic conductivity and porosity, the mean values about which the random data were generated are based on aquifer tests performed at the Freedom Avenue wellfield.

GEOLOGIC SETTING

The Canton Quadrangle lies within the northern glaciated portion of Stark County in the Appalachian Plateau Province. The topography reflects the underlying Wisconsinan glacial deposits that form the kame and kettle features, as well as the hummocky tracts of land which distinguish this region. Post-glacial drainage has modified the character of the land into that of moderate relief and gentle slopes with broad shallow floodplains (Delong and White, 1963; White, 1982). A large portion of Stark County is drained by the Tuscarawas River and its tributary system. One such tributary, Nimishillen Creek, and its tributary, the West Branch, drains the area north of Canton. The immediate area surrounding the North Canton wellfields is drained by a tributary creek of the West Branch known as the West Fork. The wellfields are located in the headwaters of a buried bedrock valley that was subsequently filled by glacial outwash and valley-train deposits to form the existing broad valley (Figure 1).

Unconsolidated Deposits

The surficial glacial deposits in Ohio were laid down by a series of ice sheets of the Erie Lobe that advanced down the Erie Basin from its center of origin in Labrador, Canada during the Pleistocene Epoch. There were four major glacial stages during the Pleistocene separated by warmer interglacial intervals. However, the bulk of the glacial drift in northeastern Ohio was deposited during the most recent glacial stage, the Wisconsinan. As the Erie Lobe advanced southward the ice sheets were funneled through the lower topographic areas between the higher divides of resistant bedrock. The advancing ice eroded resistant bedrock highs and deepened valleys and lowlands as it incorporated bedrock and surficial deposits into the ice. Valleys parallel to the direction of ice movement were made wider and more U-shaped than valleys oriented transverse to glacial flow. In Stark County, glacial erosion removed as much as 50 ft of bedrock and surficial deposits from valley walls and approximately 100 ft in some valley bottoms (White, 1982).

Sediment transported and deposited by or from glacial ice with little or no sorting by water is called till (Shaw, 1985). Fluvial deposits formed from ablation of ice margins in the proglacial environment are called outwash (Stephenson and others, 1989).

The Erie Lobe is subdivided into five lobes: the Miami Lobe, the Scioto Lobe, the Killbuck Lobe, the Cuyahoga Lobe, and the Grand River Lobe (Figure 2). During each of the four major glaciations the ice in each lobe repeatedly advanced and retreated depositing glacial material which has a distinct character for each lobe (White, 1982).

The Grand River Lobe advanced into Stark County from the northeast, whereas the Killbuck Lobe advanced into Stark

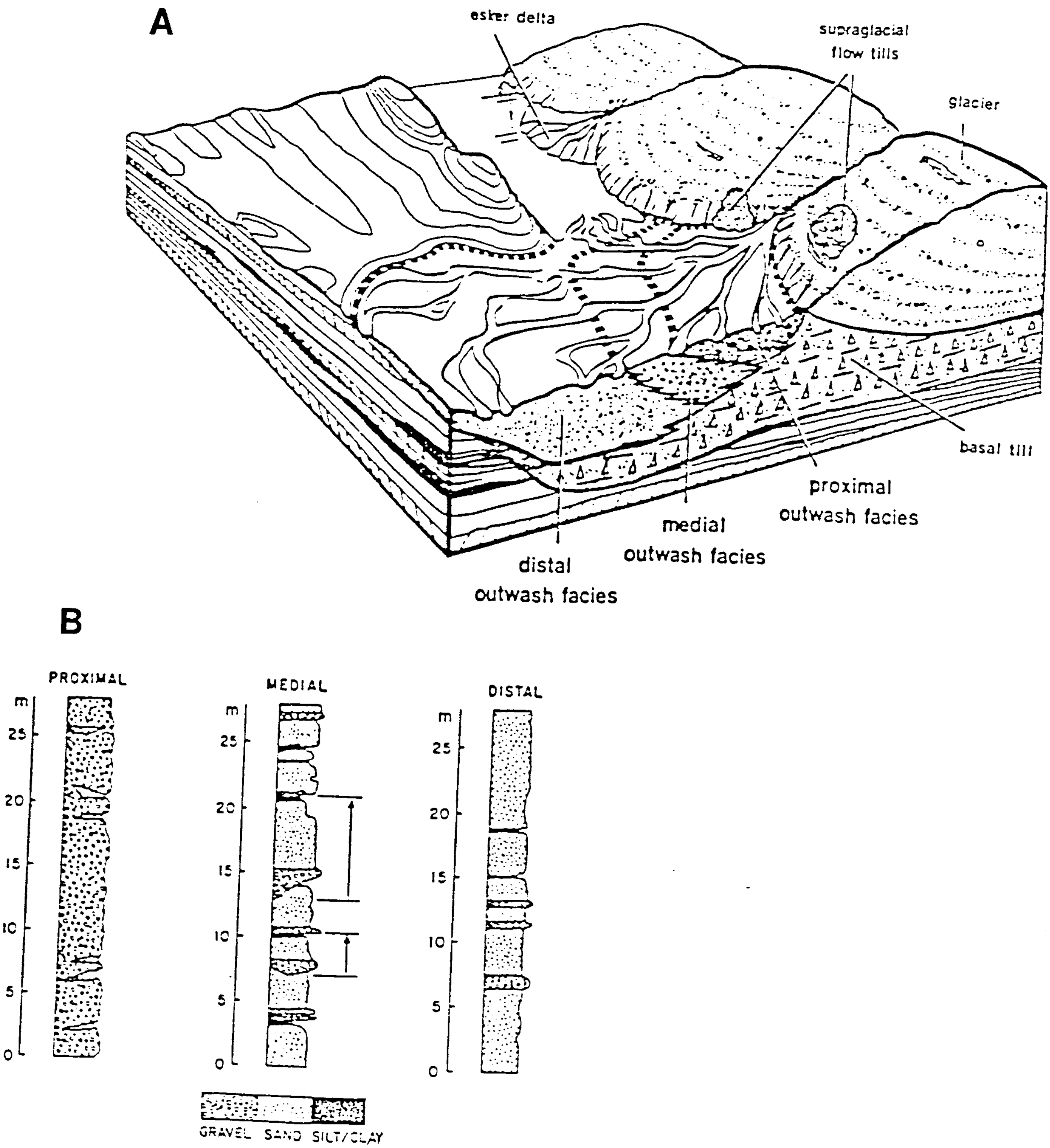
Figure 2. Map showing glacial lobes in Ohio and the confluence of the Killbuck lobe and the Grand River lobe in Stark County. The star shows the location of North Canton. (Delong and White, 1963)

County from the northwest (Figure 2). The area of central Stark County represents the confluence of the Grand River and Killbuck lobes.

Delong and White (1963) described how the outer margin of the Grand River Lobe, which deposited the Kent Moraine, adjoins the eastern margin of the Killbuck Lobe, which deposited the Buck Hill Moraine, along the valley of the West Branch of Nimishillan Creek and its tributary the West Fork. This narrow valley-train deposit appears to be an interlobate meltwater channel. The valley-train deposit follows the West Branch valley to a junction with the outwash deposits at Canton, Ohio. Contributions of meltwater from the Killbuck Lobe and the Grand River Lobe formed the valley-train deposit and outwash plain in Canton (Delong and White, 1963). Figure 3 is a conceptual facies model adapted from Miall (1983) by Anderson (1989) that may be used to depict the general condition of the outwash facies relevant to the interlobate meltwater channel in north-central Stark County. The texture of the material to the north at the county line is very coarse, cobbly to bouldery, imbricated gravel indicating deposition close to the melting ice in the proximal area. Less cobbly, medium to fine gravel exists farther south in the medial area (Delong and White, 1963).

Figure 4 shows a geologic cross section I constructed from well-log data within the valley-train deposits encompassed by the North Canton wellfields which lie adjacent

Figure 3. Hydrogeologic facies for outwash. (A) Conceptual model of the proglacial environment showing the proximal, medial, and distal facies of an outwash fan. (B) Vertical profiles for the proximal, medial, and distal facies assemblages of an outwash deposit (adapted from Miall, 1983).[13]



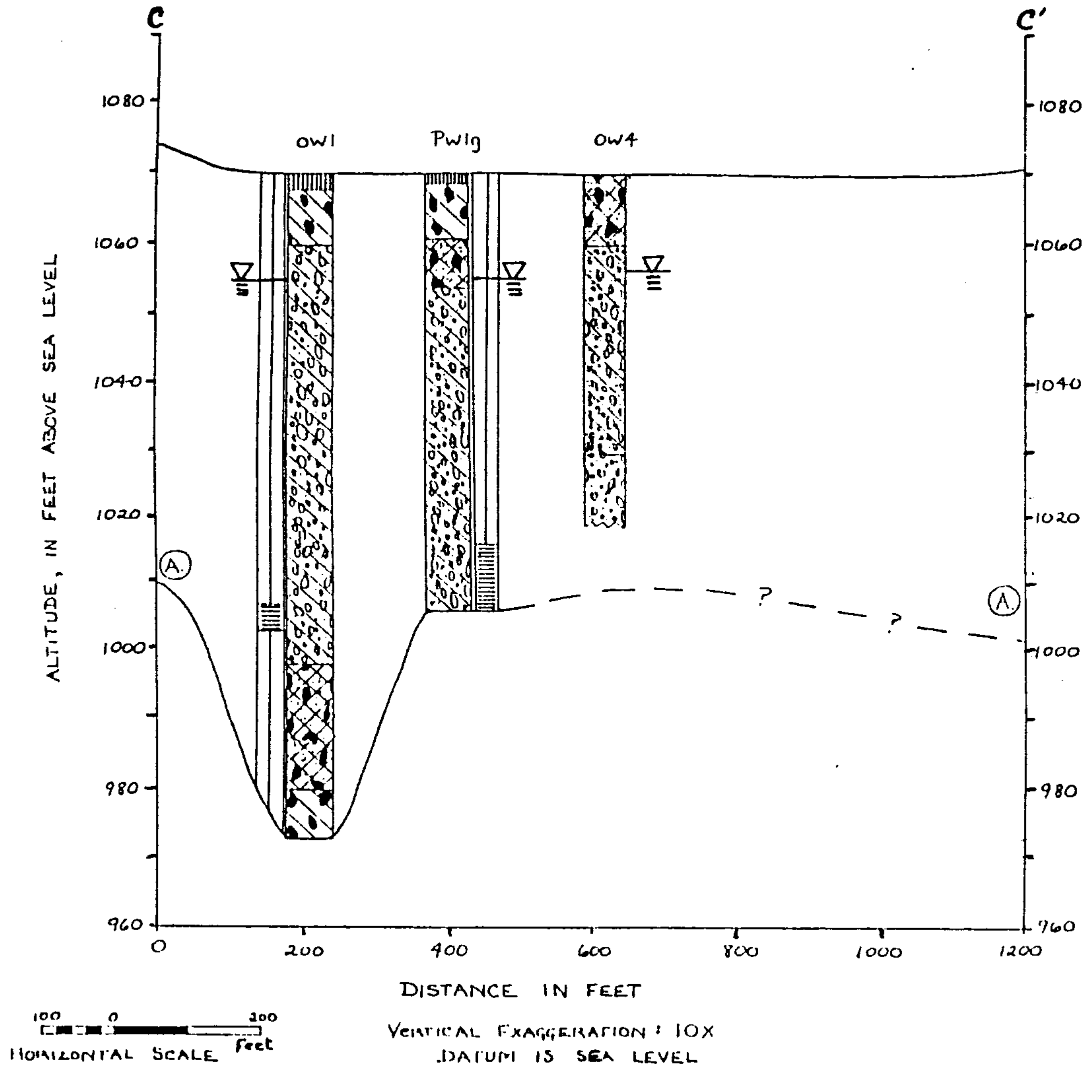
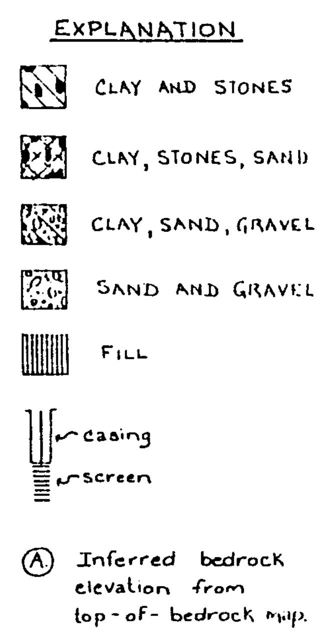


Figure 4. Geologic cross section C-C' from Freedom Avenue to Whipple Road showing detail of glacial deposits.

STATIC WATER LEVEL DEPTHS

OW1 - 14.71 ft
PW1g - 15.13 ft
OW4 - 14.08 ft



to West Fork in the interlobate meltwater channel. This area may be considered representative of a transitional-proximal to medial-outwash facies because it shows layered sequences of gravel containing sand and clay as opposed to the gravel sequences of the strictly proximal outwash facies. The higher clay content shown in this cross section may be due to the proximity to the eastern edge of the valley where till from kame terraces of the Grand River Lobe along the valley wall may have slumped off as the meltwater was reworking the valley-train deposits. Outwash is deposited by braided streams. The proximal portions generally are deposited by gravel-bed streams, whereas medial and distal portions generally are deposited by sand-bed streams. Some of the distal portions may be deposited by meandering or anastomosing streams which would increase the fine clay and silt content of the outwash in periods of overbank flow.

The glacial deposits range from 60 to 90 ft thick and form the unconfined aquifer of the region under study. In areas of continental glaciation major ground-water sources occur in buried-glacial valleys. Thus, the valley-train deposits in the interlobate meltwater channel in north-central Stark County represent the common hydrogeologic setting of a stratified-drift buried-valley aquifer. Sand and gravel deposited by meltwater streams as valley trains commonly are better stratified, better sorted, and more continuous than that deposited near the ice margin and thus they provide excellent sources for ground water (Stephenson and others, 1988). However, in the City of North Canton the principle high yielding municipal ground-water wells are completed in the even more prolific leaky-confined bedrock aquifer.

Bedrock Stratigraphy

The bedrock of the Allegheny Plateau in northeastern Ohio consists of Mississippian and Pennsylvanian strata (Figure 5). The Mississippian rocks are fine-grained siltstones and sandstones. The Pennsylvanian rocks are conglomerates, sandstones, shales, thin limestones, and coal. The glacial drift in Stark County is underlain by Pennsylvanian bedrock. The Pennsylvanian System in Ohio is divided into four formations, which in ascending order are the Pottsville Formation, the Allegheny Formation, and the Conemaugh Formation and the Monongahela Formation. The Conemaugh Formation and all younger Pennsylvanian rocks, however, have been removed by erosion in Stark County (Delong and White, 1963). The Mississippian System in Stark County is represented by the Cuyahoga Formation which consists of silty shales of the Meadville shale. Figure 6 shows a generalized stratigraphic column for Stark County depicting the various lithologies of the different formations.

The Pottsville Formation underlies the glaciated portions of most of the county. In Stark County the Pottsville Formation is believed to have a maximum thickness of approximately 400 ft (Sedam, 1973). The strata of the

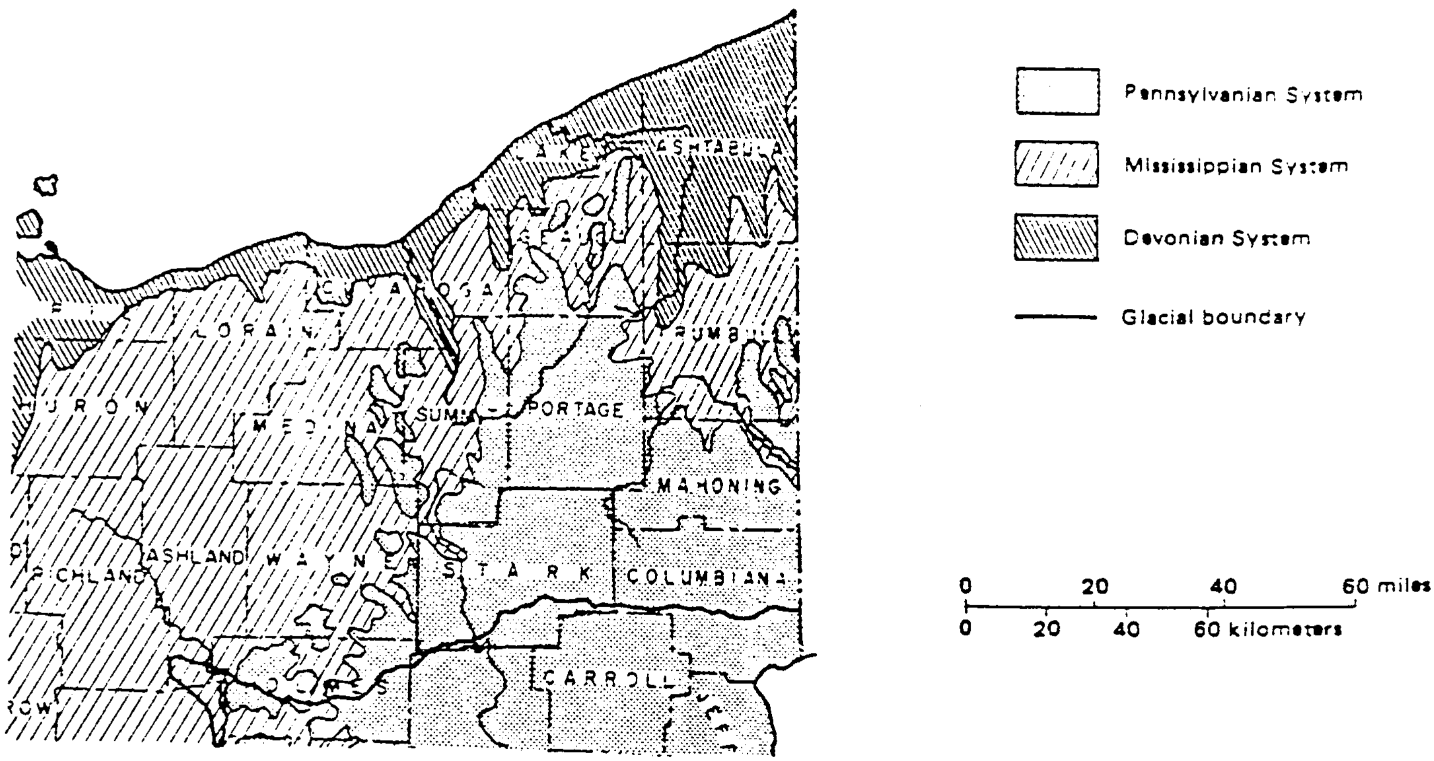


Figure 5. Bedrock geology of northeastern Ohio (White, 1982).

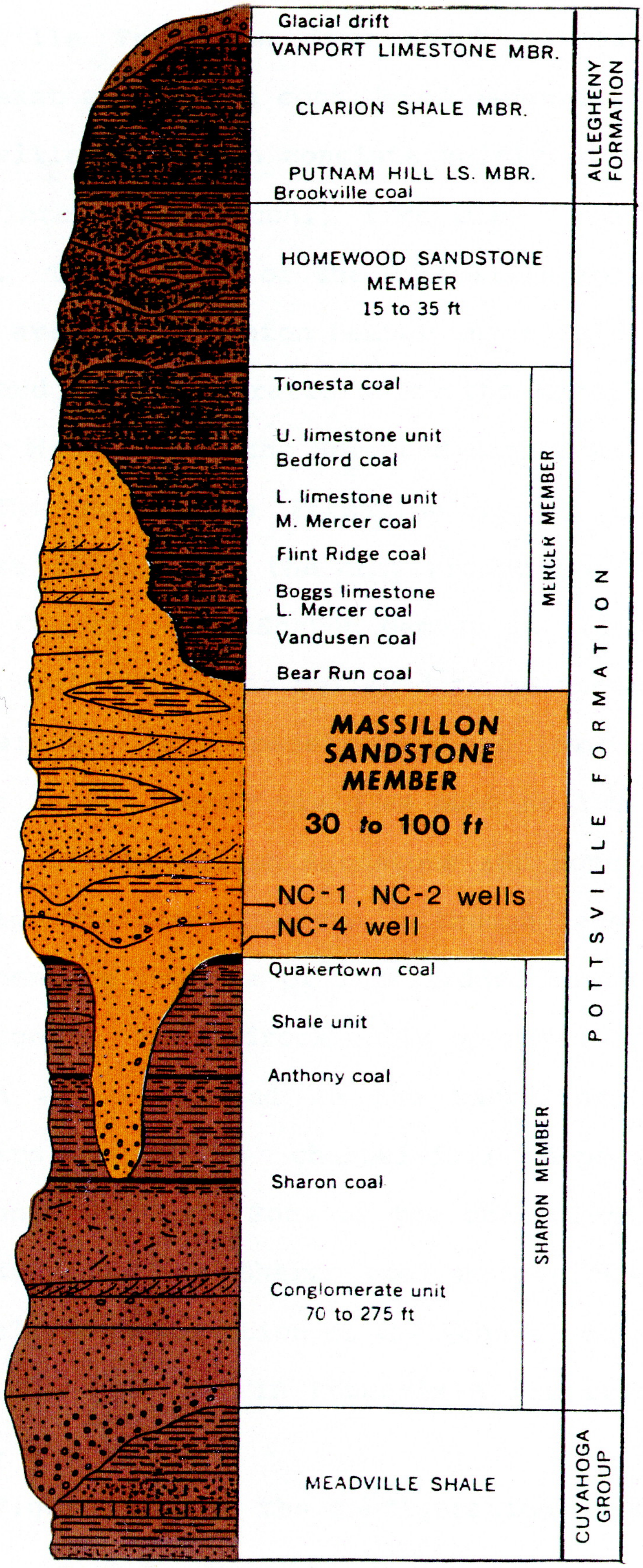


Figure 6. Generalized stratigraphic column of Stark County showing the Massillon Sandstone Member of the Pottsville Group (Sedam, 1973).

Pottsville Formation dips about 14 ft per mile to the southeast and can be considered essentially horizontal. The Pottsville Formation consists mainly of shale and sandstone with interbeds of coal, fire clay, and limestone in some areas. The members of the Pottsville Formation in ascending order are: the Sharon Member which is divided into a shaly unit and a conglomeratic unit, the Massillon Sandstone, the Mercer Member, and the Homewood Sandstone.

The Pottsville Formation is of particular interest because it contains the most productive bedrock aquifers in Stark County. The Sharon Member is the most productive of these aquifers and is believed to be about 200 feet thick in some areas. Wells penetrating the lower conglomeratic unit of the Sharon Member yield as much as 250 gallons per minute (gpm). The Massillon Sandstone and Homewood Sandstone also are high-yielding aquifers, although less so than the Sharon Conglomerate because of interbedded shale lenses within the sandstones. The bedrock wells operated by the City of North Canton are completed in the Massillon Sandstone. These aquifers represent channel-fill deposits following an erosional period. Some of the channel-fill deposits extend downward into the Sharon coal as depicted in Figure 6. A generalized description of the Pennsylvanian bedrock in Stark County is provided in Appendix A for reference (Delong and White, 1963).

Figure 7 shows the configuration of the bedrock surface

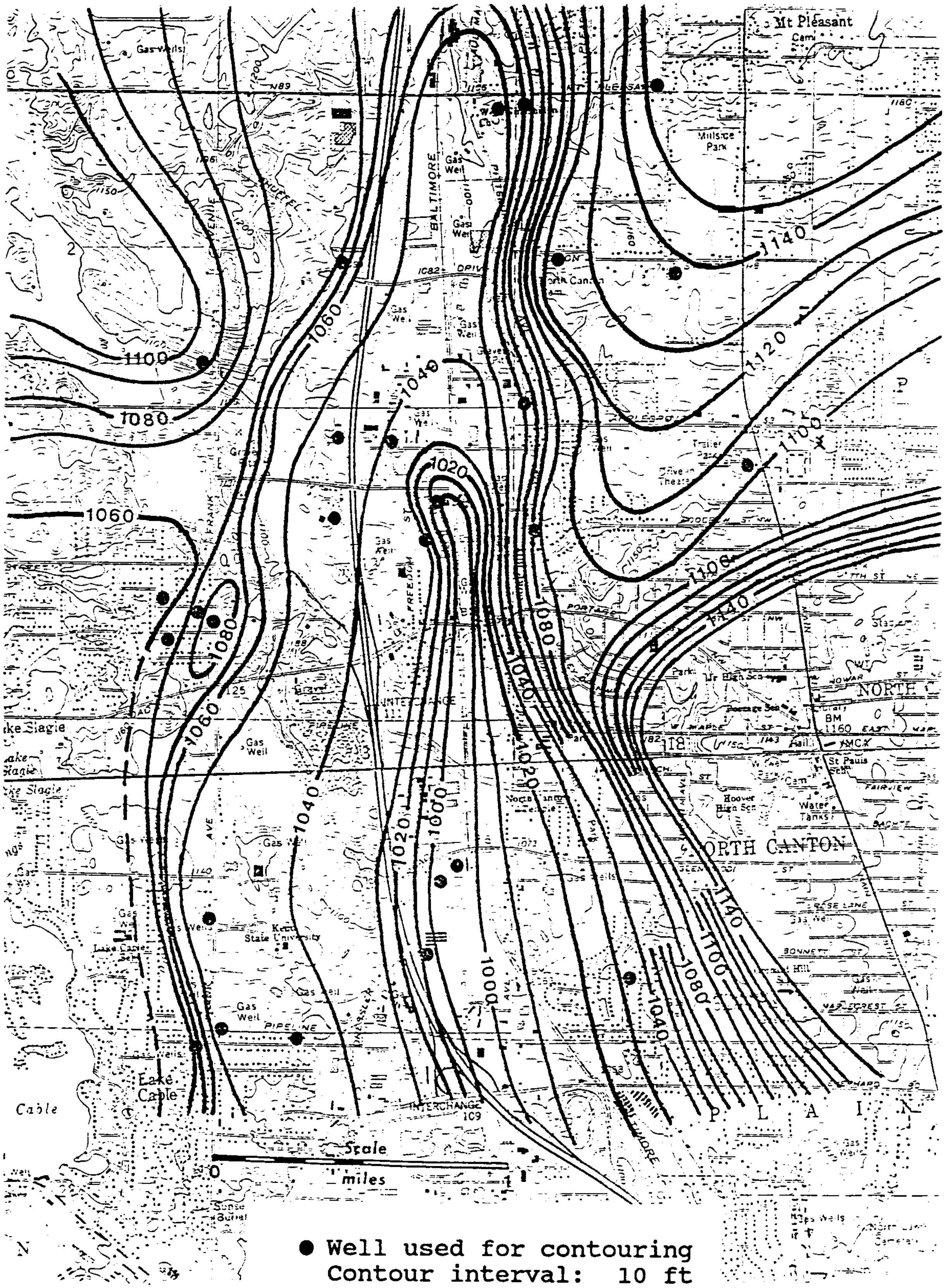


Figure 7. Top-of-bedrock contour map.

in feet above sea level superimposed on a 7.5-minute topographic map of the study area. The bedrock valley is expressed by a tightening of the contour lines along the edges of the present day valley. A bedrock high can be seen along the northwestern and eastern sides of the study area. The bedrock valley is filled with permeable glacial outwash-materials and is commonly referred to as a buried glacial valley.

FIELD STUDIES AND DATA ANALYSIS

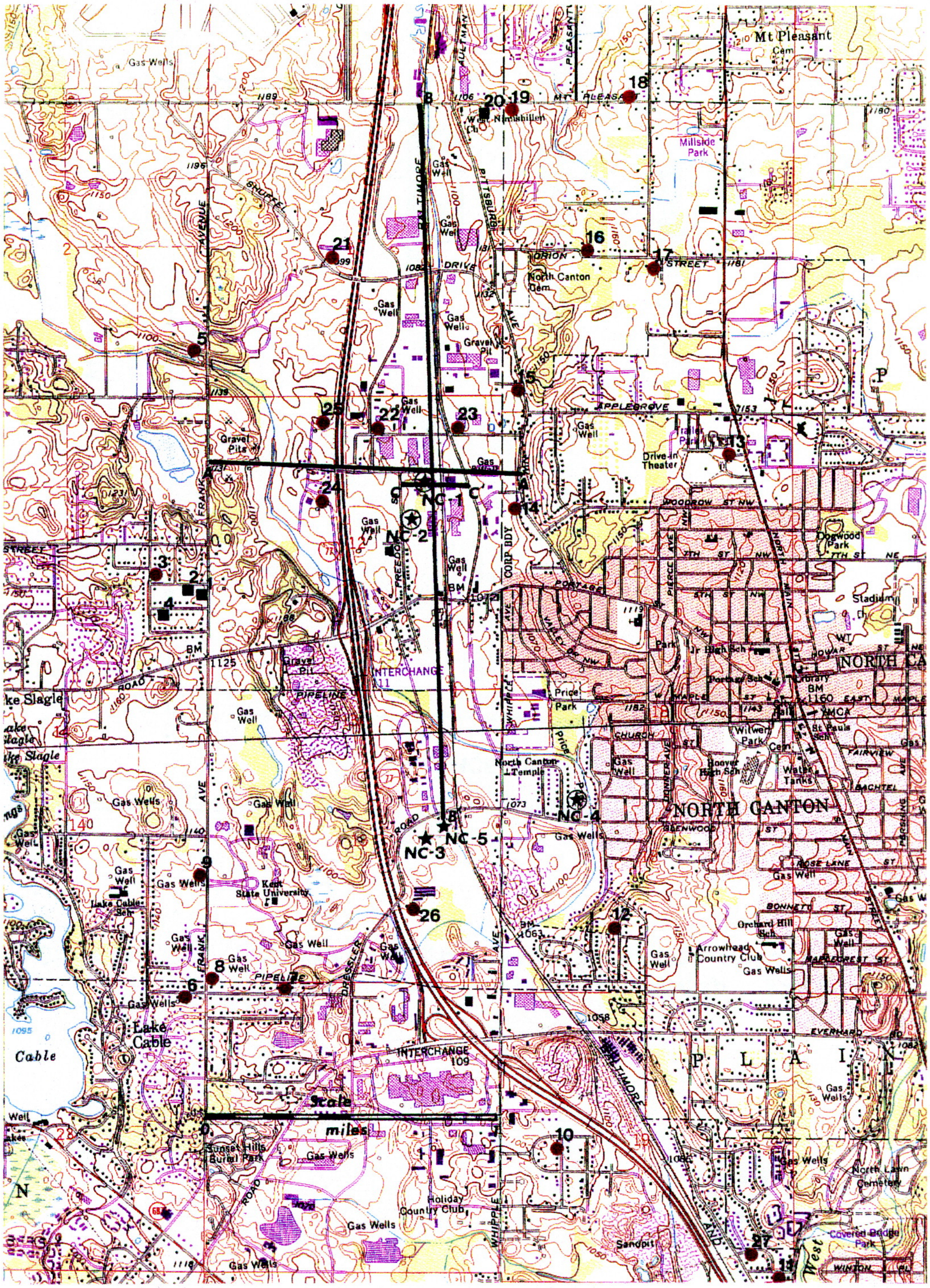
Literature and Well-Log Investigations

The initial step in the field investigations involved characterizing the Massillon Sandstone aquifer and the surrounding bedrock lithologies using available literature descriptions and data from drillers' logs, the wellfield, and the surrounding area. Delong and White (1963) described the Massillon Sandstone as a coarse to medium sandstone that is light gray on a fresh surface, although it is tan to buff because of impurities such as hematite and clay minerals. It is generally micaceous, and contains feldspar, clay, and conglomerate lenses. Massive or platy cross bedding with scour-and-fill stratification commonly are present throughout the unit (Sedam, 1973). Based on the available evidence from historic well logs, the approximate thickness of the porous Massillon Sandstone in the immediate area of the North Canton wellfields is about 90 ft thick. Delong and White (1963) explain that the lower 20 to 30 ft is massively bedded, the middle extent is medium bedded, and the upper portion is thin to medium, irregularly bedded and commonly shaly.

Geologic and hydraulic information were obtained from a number of domestic and industrial wells and their well logs throughout the study area (Appendix B). The well logs indicate that the North Canton municipal wells are completed in the Massillon Sandstone. Correlation of other nearby well logs with that of NC-1 shows that in the vicinity of the wellfield the Massillon Sandstone is capped by a semi-continuous layer of shale. The shale layer averages about 45 ft in thickness.

Figure 8 shows the orientations of geologic cross sections and the network of wells in which water levels were measured. Cross section A-A' (Figure 9) is a west-to-east cross section across the valley through the Freedom Avenue Wellfield. The open portion of NC-1 has no well screen and is in the Massillon Sandstone aquifer which is shown to be approximately 90 to 100 ft thick.

Figure 10 is a north-to-south cross section oriented along the valley through the Freedom Avenue and Dressler Road wellfields. The glacial-outwash deposits appear to thicken in a southerly direction, down the valley toward the thicker glacial-outwash plain that exists south of North Canton. The Massillon Sandstone aquifer is exposed to the open part of the borehole of NC-1. Its exact correlation to other sandstone layers within the valley is limited by the lack of well-log data along section line B-B'. (The Timken Company well, indicated by "T" in Figure 10, was projected a considerable distance from its location on the northwestern topographic high near the airport for use in correlating the Massillon Sandstone within the valley.)



- ● Well control
- ★ Municipal well
- A ——— A' Cross-section line

Figure 8. Map of well locations and cross section orientations.

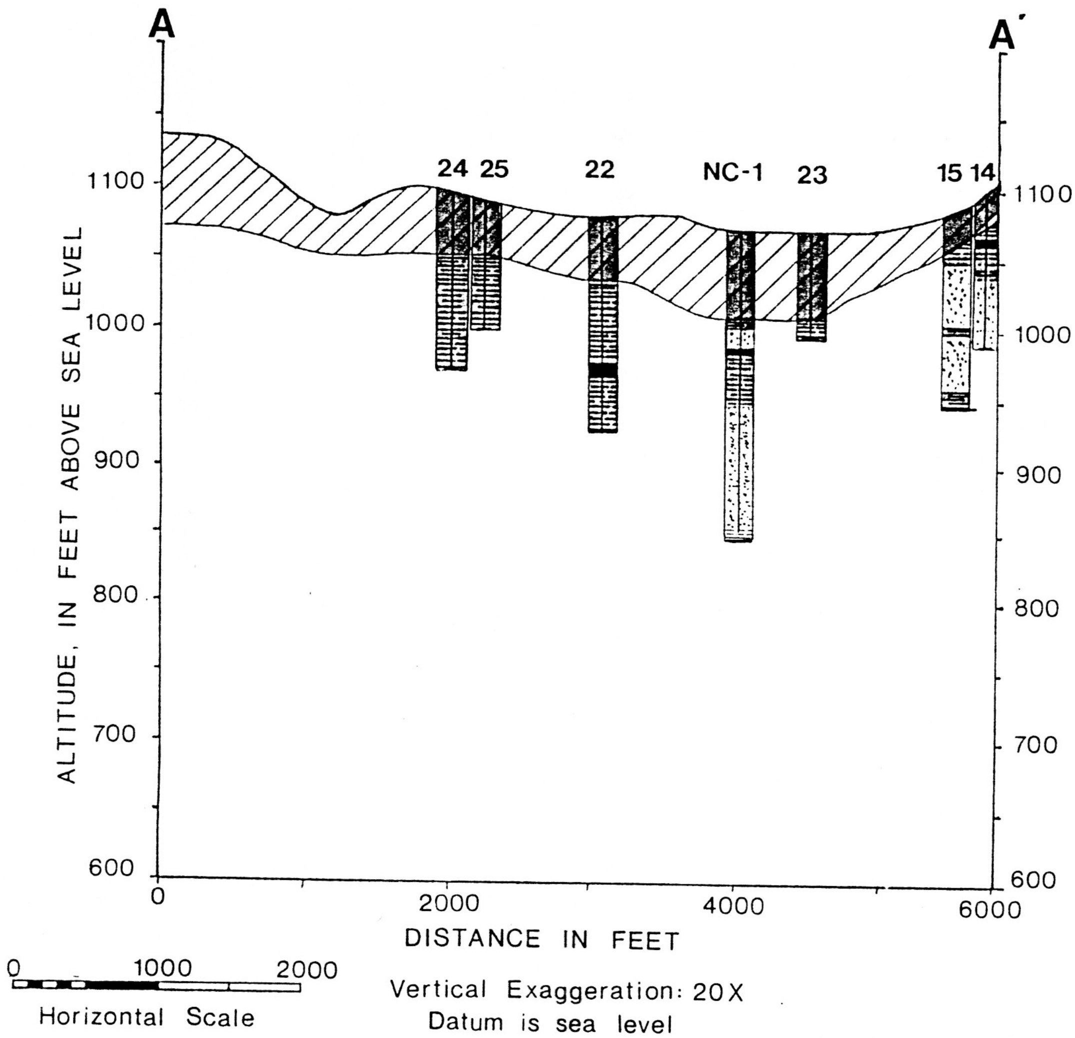
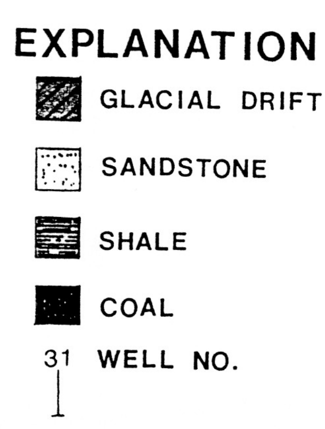


Figure 9. Cross section A-A': west-to-east cross section across the valley through Freedom Avenue Wellfield.



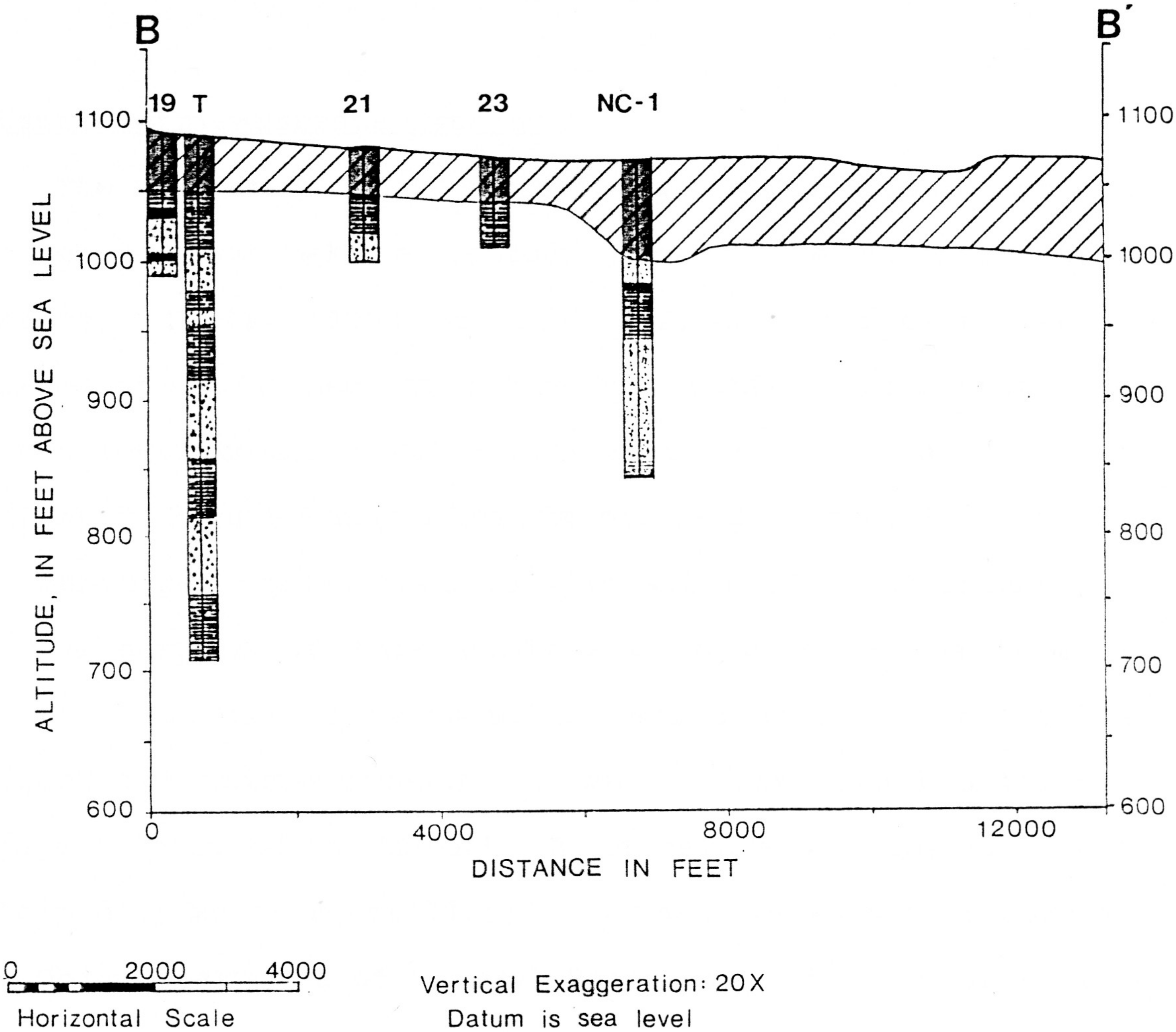
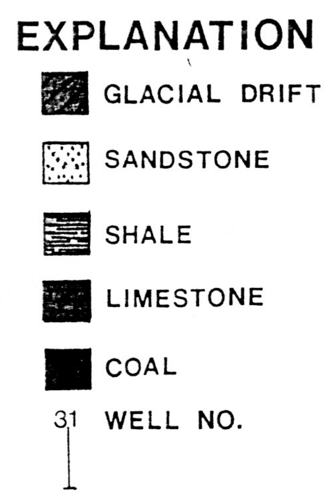


Figure 10. Cross section B-B': north-to-south cross section along the valley.



Potentiometric-Surface Mapping

The next stage in characterizing the Massillon Sandstone aquifer was to make a contour map of the potentiometric surface. Fetter (1988, p. 102) defined the potentiometric surface of a confined aquifer as "the surface representative of the level to which water will rise in a well cased to the aquifer." Figure 8 shows the network of domestic, industrial, and municipal wells used to make water-level measurements. As the purpose of this study was to examine the bedrock aquifer, not all of these wells were used to construct the bedrock potentiometric-surface map. The actual drillers' logs are included in Appendix B for reference. The logs were obtained by xeroxing drillers' log that are kept on record at the Ohio Department of Natural Resources- Division of Water.

Water levels were measured in these wells in May 1989 at seasonally high ground-water levels and again in October 1989 at seasonally low ground-water levels. Table 1 summarizes these water-level data. Also listed on this table are differences in water levels occurring between the two periods of measurement. The average difference using in water levels was 1.3 ft and is considered negligible. (The average difference in water levels does not include the water level difference for NC-4 because this well was pumping at the time the water level was measured.) As a result, the May 1989 measurements were used to depict the steady-state

Table 1

Summary of Measured Water-Level Data

CMS No.	Water-Level Measurement (feet above sea level) May 1989	Oct. 1989	Difference
NC-1	1039	1038	1
NC-2	1024	1022	2
NC-3	1042	1038	4
NC-4	1051	996	55 *
NC-5	1019		
CMS-1	1110	1110	0
CMS-2	1115	1115	0
CMS-3	1113		
CMS-4	1114	1113	1
CMS-5	1091	1090	1
CMS-6	1090		
CMS-7	1049		
CMS-8	1085		
CMS-9	1083	1083	0
CMS-10	1040	1040	0
CMS-11	1012		
CMS-12	1104	1102	2
CMS-13	1124	1129	-5
CMS-14	1065		
CMS-15	1053	1051	2
CMS-16	1089	1087	2
CMS-17	1146	1146	0
CMS-18	1098	1095	3
CMS-19	1090	1082	8
CMS-20	1086	1085	1
CMS-21	1081		
CMS-22	1064		
CMS-23	1052		
CMS-24	1065		
CMS-25	1067		
CMS-26	1050		
CMS-27	1042		

* not included in average value

configuration of the potentiometric surface of the Massillon Sandstone aquifer.

Figure 11 shows the potentiometric surface overlain on the topographic map of my study area. The potentiometric lines represent contour lines connecting points of equal ground-water elevation above sea level. Ground water flows perpendicularly across the potentiometric surface lines from high potential energy to low potential energy. Ground-water flow converges toward the axis of the valley from the valley walls, and down gradient beneath the industrial park in the study area.

Aquifer Test

In September 1989, I helped perform an aquifer test in conjunction with students of an 800-level seminar course under the direction of my advisor and in association with The Ohio Drilling Company, the technical consultant of the City of North Canton. An aquifer test is a field technique used to determine values of hydraulic properties by stressing the aquifer by pumping water from a well for an extended period of time while recording the drawdown in the pumping well and surrounding observation wells. The drawdown data can be used in association with various equations representing different conceptual models (boundary conditions) to determine the hydraulic properties of the aquifer. The specific equations and assumptions used in the analysis are based on the geologic

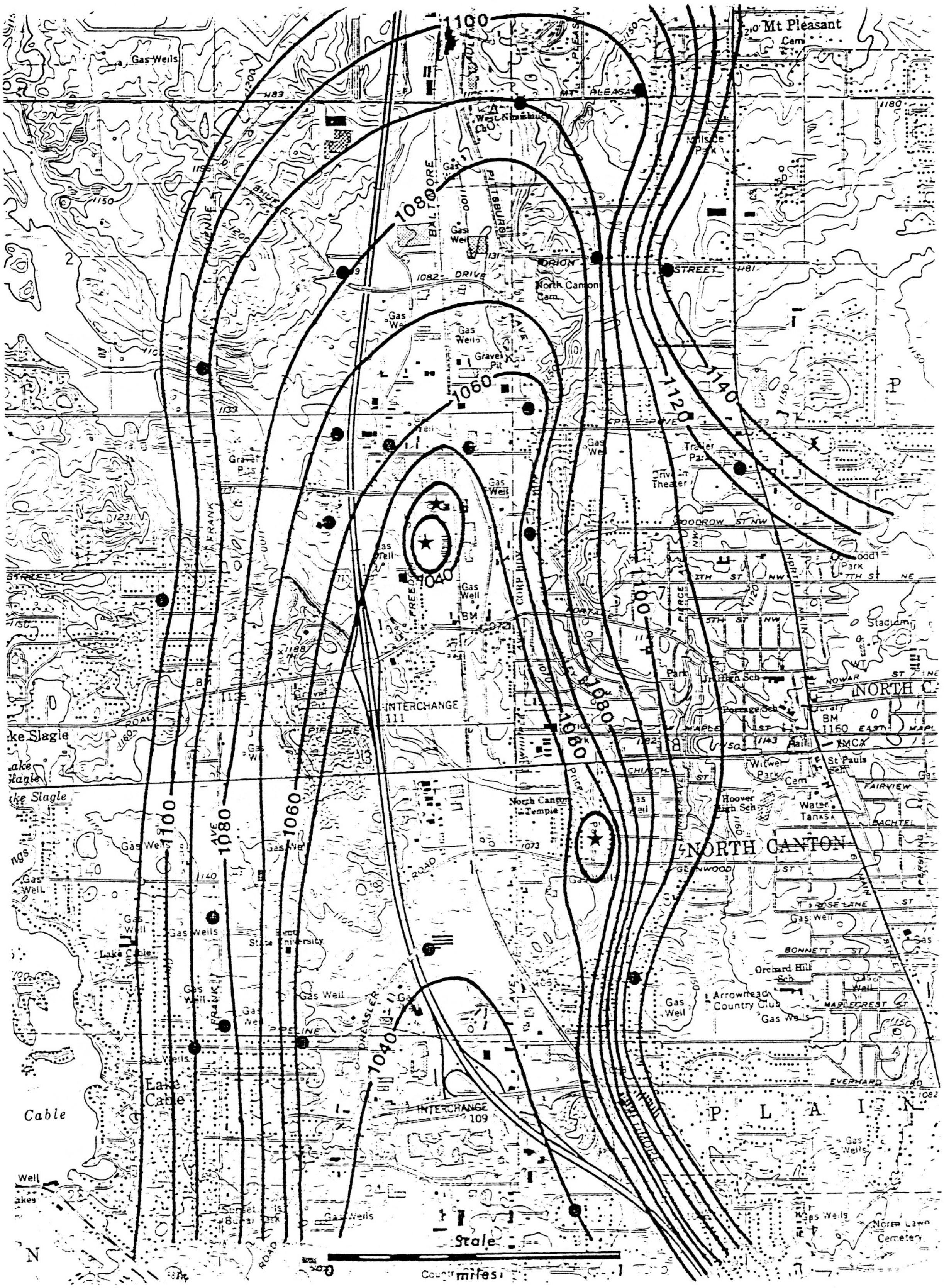


Figure 11. Bedrock potentiometric-surface map.

● Well * Municipal well

——— Equipotential line Contour interval: 10 ft setting of the aquifer under study. The analytical model chosen was the Hantush-Jacob equation (Hantush and Jacob, 1954) for analyzing leaky-confined aquifers with no storage in the overlying leaky-confining layer.

The aquifer test was set up at the Freedom Avenue Wellfield in the manner shown in Figure 12. The pumped well was NC-1, the contaminated bedrock well. The observation well was NC-2 which is located 712 feet south of NC-1. The duration of pumping was 1075 minutes or about 18 hours. The average discharge rate (Q) during the test was determined to be 1,454 gpm. The pumping well, NC-1, is an open borehole with 24-inch diameter casing extending to a depth of 198 feet. The well initially was drilled in 1938 to a depth of 209 feet but has since filled up with sediment to a depth of 198 feet. The description on the driller's log indicates sand and gravel deposits with clay from 0 to 64 ft, shale with thin layers of coal and sandstone from 64 to 109 ft, and sandstone from 109 to 198 ft. In this well, the productive portion of the Massillon Sandstone is the lower 89 feet. The observation well, NC-2, also is completed as an open borehole and has a 24-inch diameter casing extending to a depth of 211 feet. This well was drilled in 1940. An incomplete driller's log exists for this well which only indicates sand, gravel and clay deposits from 0 to 11 ft. However, NC-4 about one and a half miles south and at about the same elevation, showed that a thick sandstone was found between the depths of 116 to

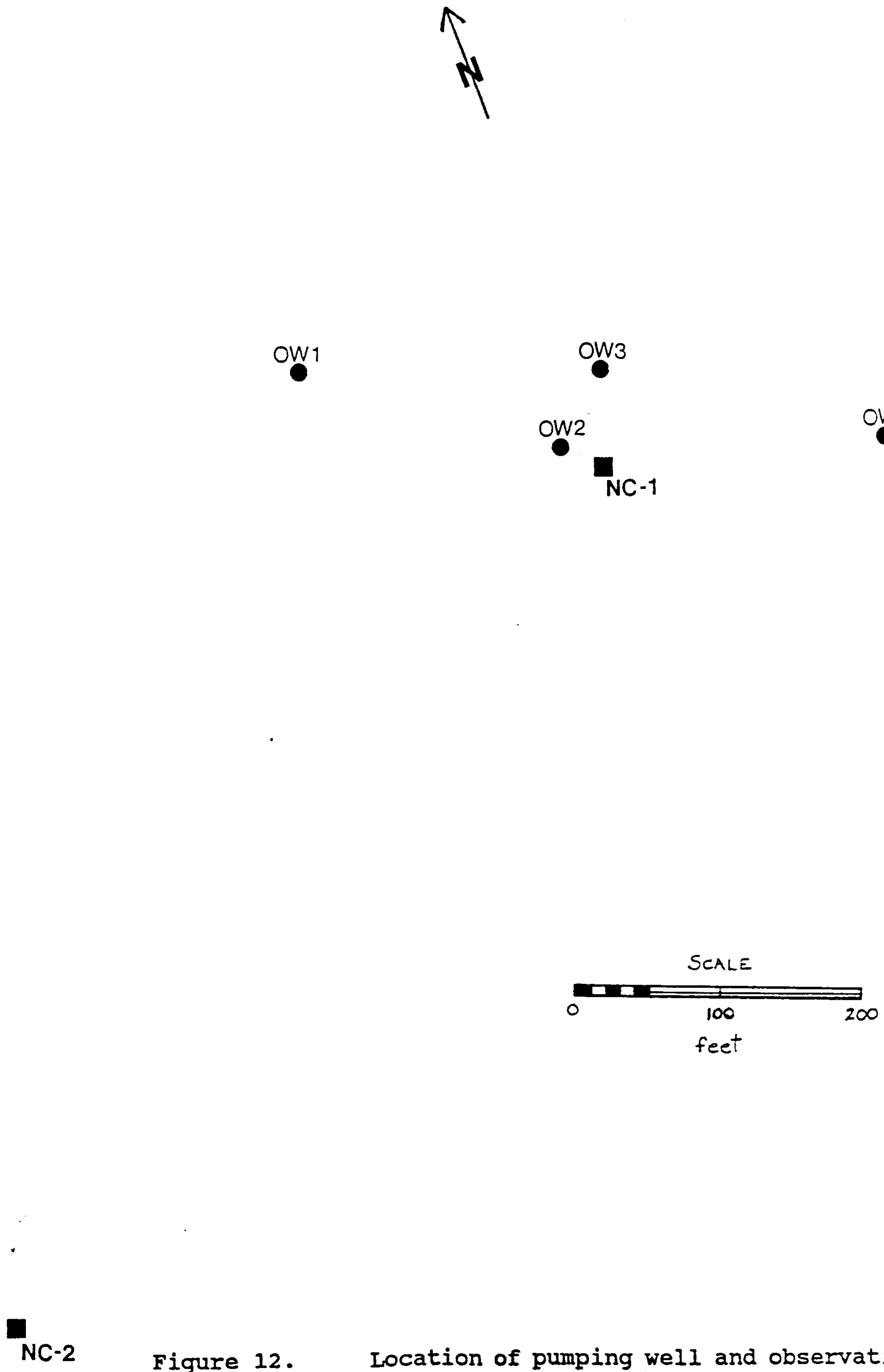


Figure 12. Location of pumping well and observation wells used during the aquifer test.

207 ft and 213 to 323 ft. It is assumed that in NC-1 and NC-2 the Massillon Sandstone aquifer is between depths of about 116 to 211 ft.

The analytical model (Hantush-Jacob equation) used to determine values of hydraulic parameters requires the following simplifying assumptions (Fetter, 1988) as applied to the Freedom Avenue Wellfield:

1). The observation well (NC-2) was pumped at a constant rate for municipal use before, during, and after the aquifer test.

2). NC-1, the pumping well, was shut in for two days and pumped at a constant discharge rate during the pumping test.

3). Barometric pressure changes during the test were not significant.

4). Water was discharged instantaneously from storage in the pumped aquifer.

5). The pumped aquifer has an infinite extent with negligible slope and has uniform thickness in the area influenced by the test.

6). The bedrock aquifer is isotropic and homogeneous.

7). NC-1 and NC-2 fully penetrate the aquifer.

8). There was no pre-pumping trend to water levels in either NC-1 or NC-2.

9). Leakage through the overlying confining layer was vertical and proportional to the drawdown or vertical hydraulic gradient.

10). The water level in the glacial aquifer overlying the confining layer was constant during the test.

11). Storage in the confining layer is negligible.

The Hantush-Jacob equation for leaky-confined aquifers as mathematically defined by Fetter (1988) is

$$s = Q/(4\pi T)*W(u,r/B)$$

where

s = drawdown (ft),
Q = discharge rate (ft^3/d),
T = transmissivity (ft^2/d),
r = radial distance to observation well (ft),
S = storativity,
t = time (days), and
B = leakage factor (ft^2)

and

$$u = r^2S/(4Tt)$$

$$B = (Tb'/K')^{½}$$

where

b' = confining layer thickness (ft), and
K' = vertical hydraulic conductivity of the confining layer (ft/d).

Determination of the function W(u,r/B) for specific values of u was obtained by plotting the time versus drawdown data from the aquifer test and then using the standard type-curve matching graphical method using theoretical curves computed by Hantush and Jacob (1954) (Fetter, 1988). Figure 13 shows the time versus drawdown plots for the pumping well, NC-1, and the observation well, NC-2. The data for NC-1 and NC-2 fall closely in line with the type curves with values of r/B = 0.01 for NC-1, and r/B = 0.2 for NC-2. The good fit of these data points indicates that the Hantush-Jacob model

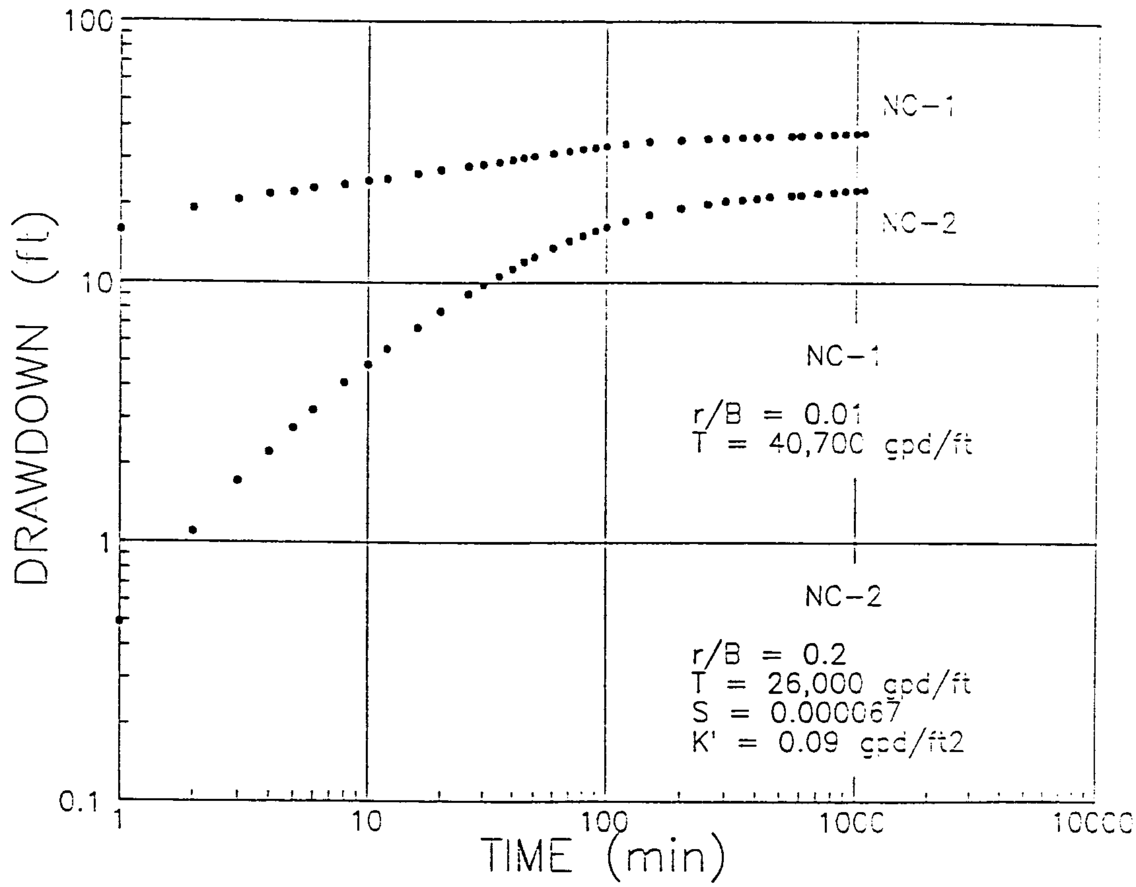


Figure 13. Time versus drawdown plots for the pumping well, NC-1, and the observation well, NC-2.

T = Transmissivity
S = Storativity
K'= Vertical hydraulic conductivity of confining layer

(equation) is a good conceptual model for representing the flow system at the North Canton wellfields.

The hydraulic-conductivity values computed from the aquifer test data from NC-1 and NC-2 were 60 ft/d and 38 ft/d, respectively. The arithmetic average of these values is 49 ft/d which represents our best-estimate value of hydraulic conductivity for the Massillon Sandstone aquifer. The other best-estimate values of the hydraulic properties are a transmissivity of 4,460 ft^2/d, a storativity of 0.00005, and a vertical hydraulic conductivity of the confining layer of 0.012 ft/d. Table 2 summarizes the individual values of hydraulic parametes computed for each well and the best-estimate values obtained from the aquifer test. The best-estimate porosity value of 25 percent is within the range of values cited for sandstone (0.14 to 0.49) given by Mercer and others (1982).

Table 2. Summary of individual values of hydraulic properties computed for each well and the best-estimate values obtained from the aquifer test.

	NC-1	NC-2	BEST ESTIMATE
T	5,480 ft^2/d	3,481 ft^2/d	4,460 ft^2/d
K	60 ft/d	38 ft/d	49 ft/d
S	-----	0.00005	0.00005
K'	-----	0.012 ft/d	0.012 ft/d

DELINEATION OF TRAVELTIME-RELATED CAPTURE ZONES

The process of delineating traveltime-related capture zones was based on developing an analytical model that could be used to predict ground-water flow in the region under study. Analytical methods including the principle of superposition, an appropriate well-hydraulics equation, and particle-tracking analysis were applied to a conceptual flow model constructed from geologic, hydraulic, and pumpage data for the North Canton wellfields. Figure 14 is a generalized depiction of the analytical model used to represent the geologic conditions at the North Canton wellfields. The upper aquifer in the diagram corresponds to the glacial-drift aquifer, the leaky confining layer corresponds to the shale layer, and the lower aquifer corresponds to the Massillon Sandstone aquifer.

The principle of superposition is a mathematical principle that can be adapted to linear equations to solve a problem involving multiple input parameters that can be simplified to the sum of the solutions to the set of individual input conditions (Reilly and others, 1987). The principle of superposition enables drawdown at a specified location to be added to drawdown caused by well interference from other wells at that location. A semianalytical flow model was constructed using the Hantush-Jacob equation to compute drawdowns produced by the three bedrock wells at

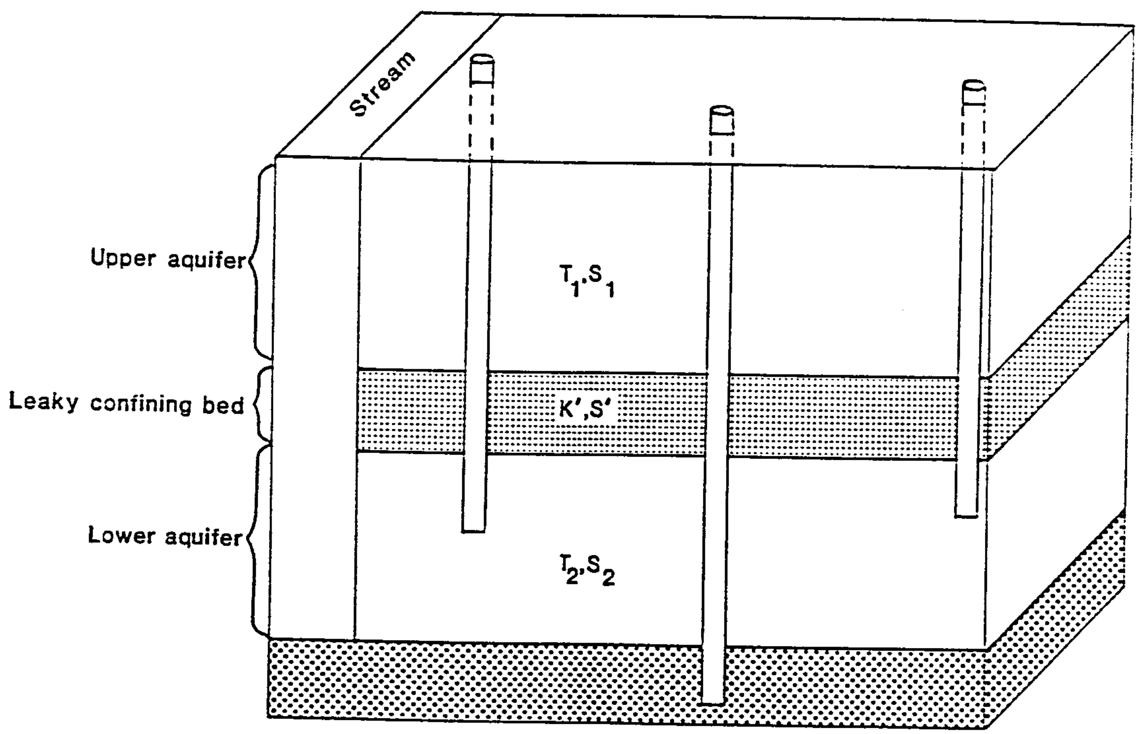


Figure 14. Generalized depiction of the analytical model used to represent the geologic conditions at the North Canton wellfields (Peters, 1987).

specified locations defined by a uniform grid overlain on the study area. Computed drawdowns then were subtracted from regional water levels to simulate the configuration of the potentiometric (water level) surface produced by pumping the three wells completed in the Massillon Sandstone.

Deterministic Approach

The best-estimate values listed in Table 2 are the values of aquifer parameters used in various computer programs to predict the 1-year capture zones of the three bedrock wells based on a deterministic approach. A deterministic approach is based on best-estimates or average values of hydraulic parametes and does not account for spatial variations in these values (El-Kadi, 1984).

Ground-Water Flow Model

Figure 15 shows the regional pre-pumping background potentiometric surface of the study area that was constructed by contouring the water levels measured in the network of wells. A contour plotting program, SURFER (Golden Graphics, 1989), averaged these regional hydraulic heads over a rectangular grid having a 500 by 500 ft spacing and stored these values in a file. The CAPZONE program (Bair and others, in review) was used to compute drawdowns at the intersections of a regularly-spaced rectangular grid using the Theis equation or the Hantush-Jacob equation and to subtract

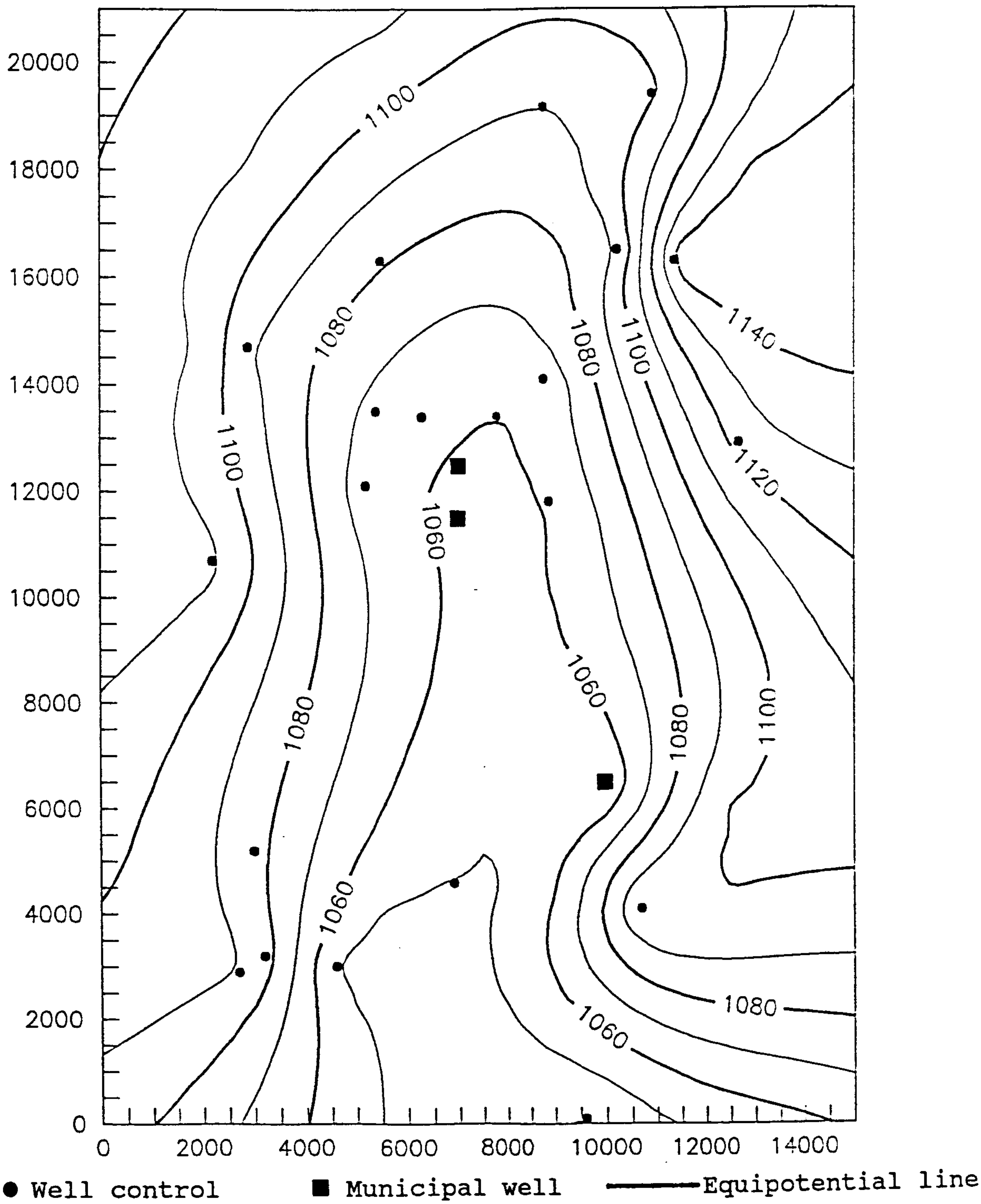


Figure 15. Regional pre-pumping background potentiometric-surface map.
(Scales in feet.) Contour interval: 10 ft

computed drawdowns from regional hydraulic heads designated at the same rectangular grid locations.

Figure 16 is a plot contoured by SURFER and computed by CAPZONE of the regional drawdown produced by pumping NC-1, NC-2, and NC-4 using best-estimate parameter values and the normal pumping rates of the wells. In CAPZONE these predicted drawdowns are subtracted from the background hydraulic heads at each grid node. Figure 17 shows the predicted hydraulic-head distribution as contoured by SURFER. The three bedrock wells are shown as solid squares and the domestic and industrial wells are shown as solid circles. The measured hydraulic heads in the network of wells are posted on the figure and indicate that the overall predicted potentiometric surface generally agrees with measured water levels (see Figure 16).

Particle-Tracking Analysis

Traveltime-related capture zones were computed using the predicted hydraulic-head distribution and the GWPATH program. GWPATH computes a two-dimensional, steady-state velocity vector field at the intersections of a rectangular grid using values of hydraulic head, hydraulic conductivity, and porosity defined at each grid intersection (Shafer, 1987a, 1987b, 1990). The trajectory (flowpaths) of particles placed anywhere in the velocity field can be traced either upgradient as a reverse flowpath or downgradient as a forward flowpath.

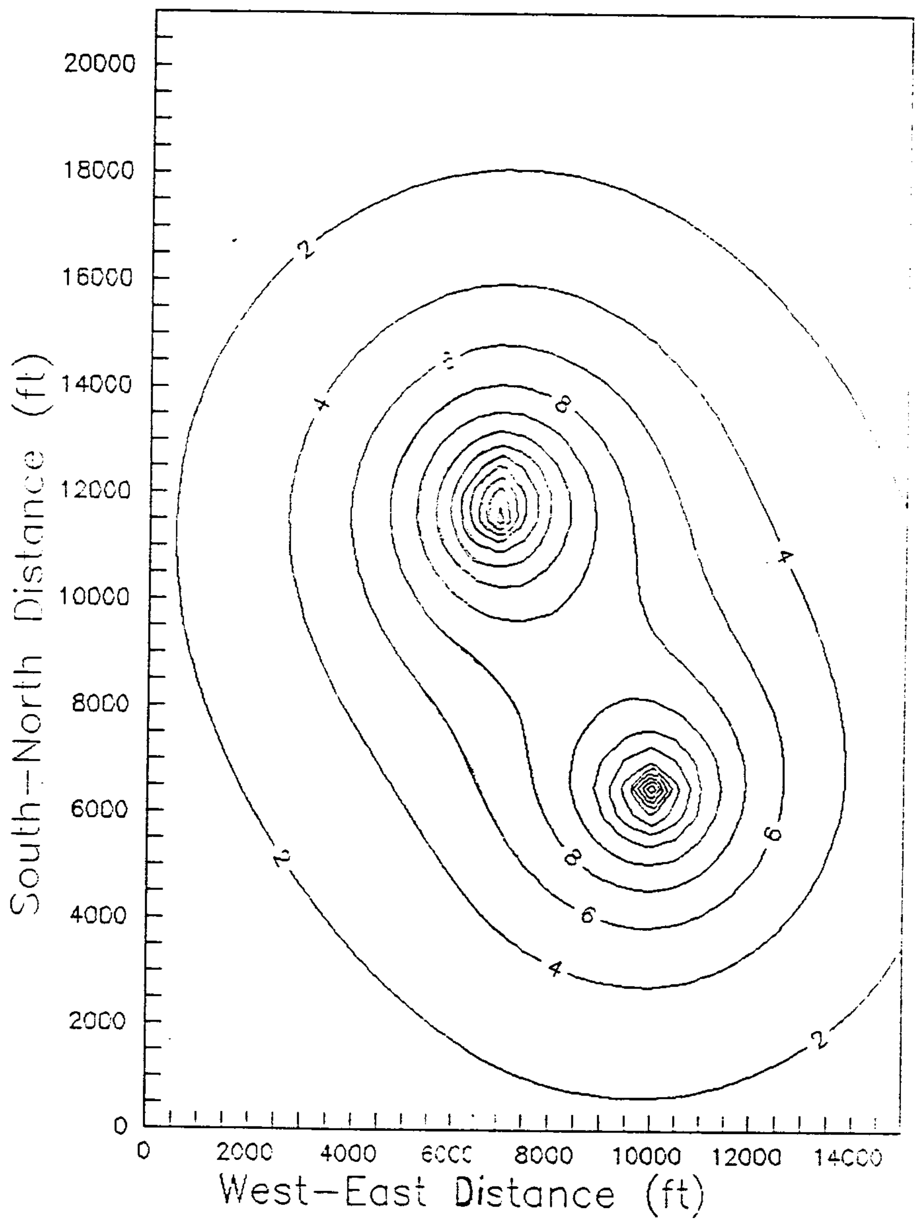
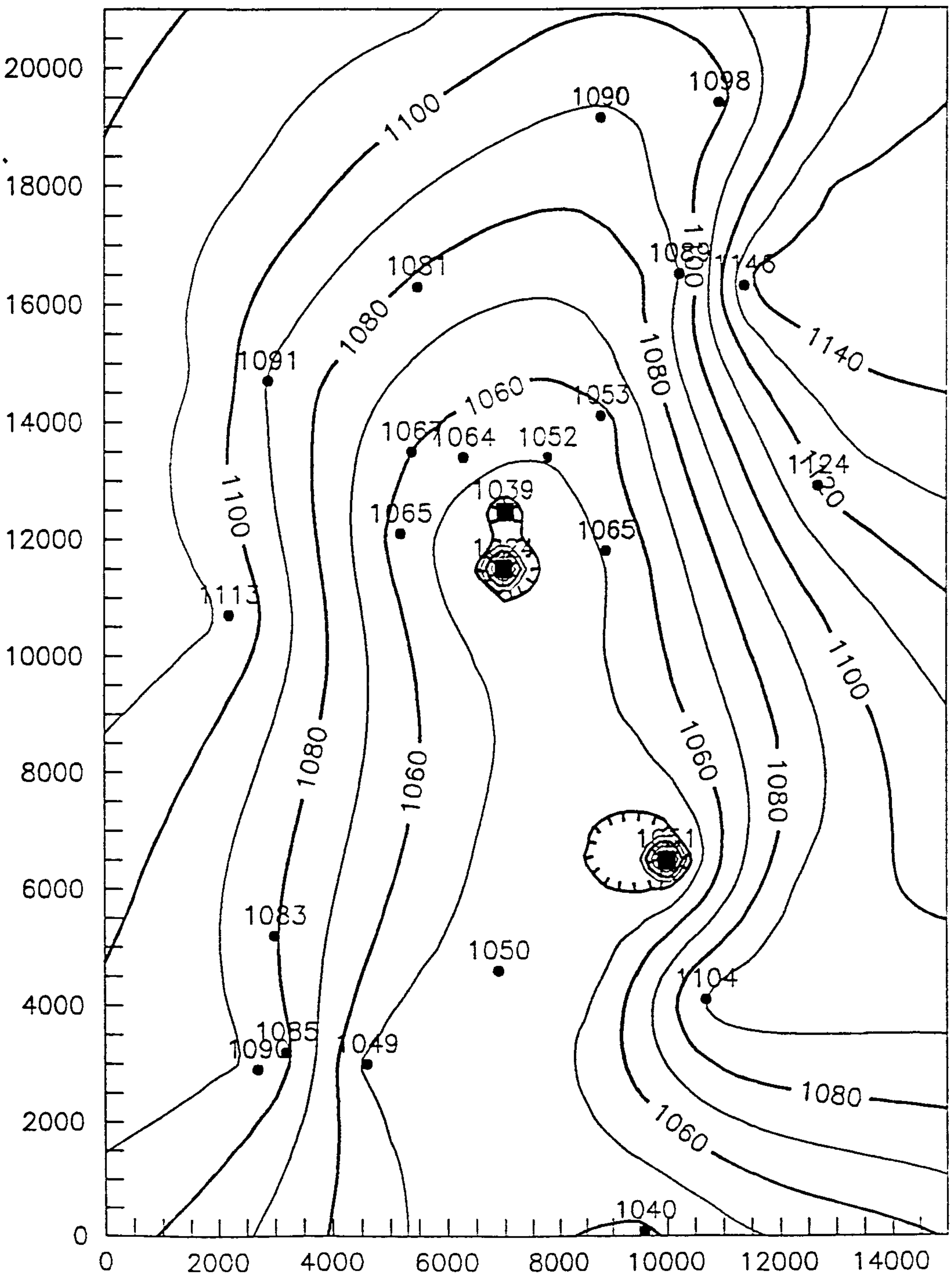


Figure 16. Predicted drawdown around each pumping well as computed in CAPZONE.

——— Drawdown contour Contour interval: 2 ft

(Scales in feet.)



● Measured water level ■ Municipal well
——Equipotential line Contour interval: 10 ft

Figure 17. Predicted potentiometric surface based on best-estimates of hydraulic parameters.(Scales in feet.)

Figure 18 is an example of the projected 5-year forward-tracked flowpaths from potential contaminant sources in the study area. Sites 1 to 6 all show flowpaths that lead into the immediate vicinity of one of the municipal wells within this 5-year period.

The traveltime-related capture zones of the bedrock wells were computed by placing 36 particles in a circle surrounding the simulated pumping wells and tracking their reverse flowpaths as if the particles of water were being pushed back upgradient for a specified period of time (e.g. one year). The loci of the flowpath endpoints after a traveltime of one year delineates the outline of the 1-year capture zones.

Figure 19 shows the calculated flowpaths and the 1-year capture zones of NC-1, NC-2, and NC-4 using the best-estimate parameter values. The capture zone of NC-1 well is smaller than the other two wells because the normal pumping rate of NC-1, 320,000 gpm, is lower than the normal pumping rates of NC-4 and NC-2 which are both pumped at a rate of 1,440,000 gpm. NC-1, which is polluted with trichlorethylene, a volatile organic chemical, is being pumped at a lower rate to prevent NC-2 from capturing the contaminated water. Figure 20 depicts the 2-year capture zones for the wells to give an indication of the increase in areal extent for a 2-year simulation. Table 3 lists the areas of the 1-year capture zones of these wells using the best-estimate parameter values. Capture-zone areas were computed using a FORTRAN program which

1 Off-ramp of I-77 and 76 Truckstop

2 Shuffel Rd. and Freedom Ave. Intersection (Industrial Park)

3 Shuffel Rd. and Pittsburg Ave. Intersection (outskirts of Industrial Park)

4 Strausser and Whipple Ave. Intersection (Industrial Park)

5 Portage Rd. and Whipple Ave. Intersection (outskirts of Industrial Park)

6 Whipple Ave. and Dressler Intersection

7 Off-ramp of I-77 at Everhard Rd. (High traffic use)

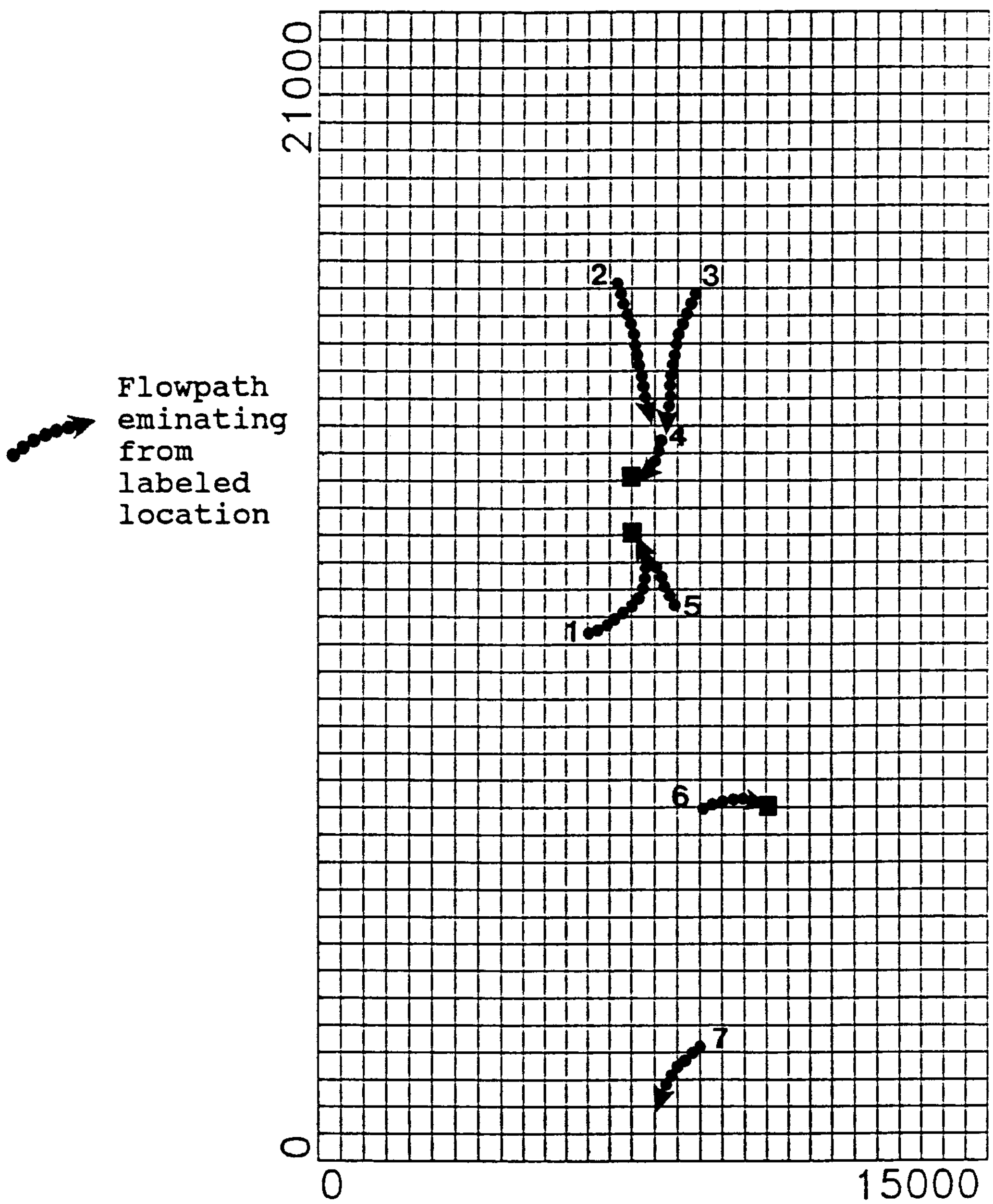


Figure 18. Projected 5-year forward-tracked ground-water flowpaths from potential contaminant sources in the study area.(Scales in feet.)

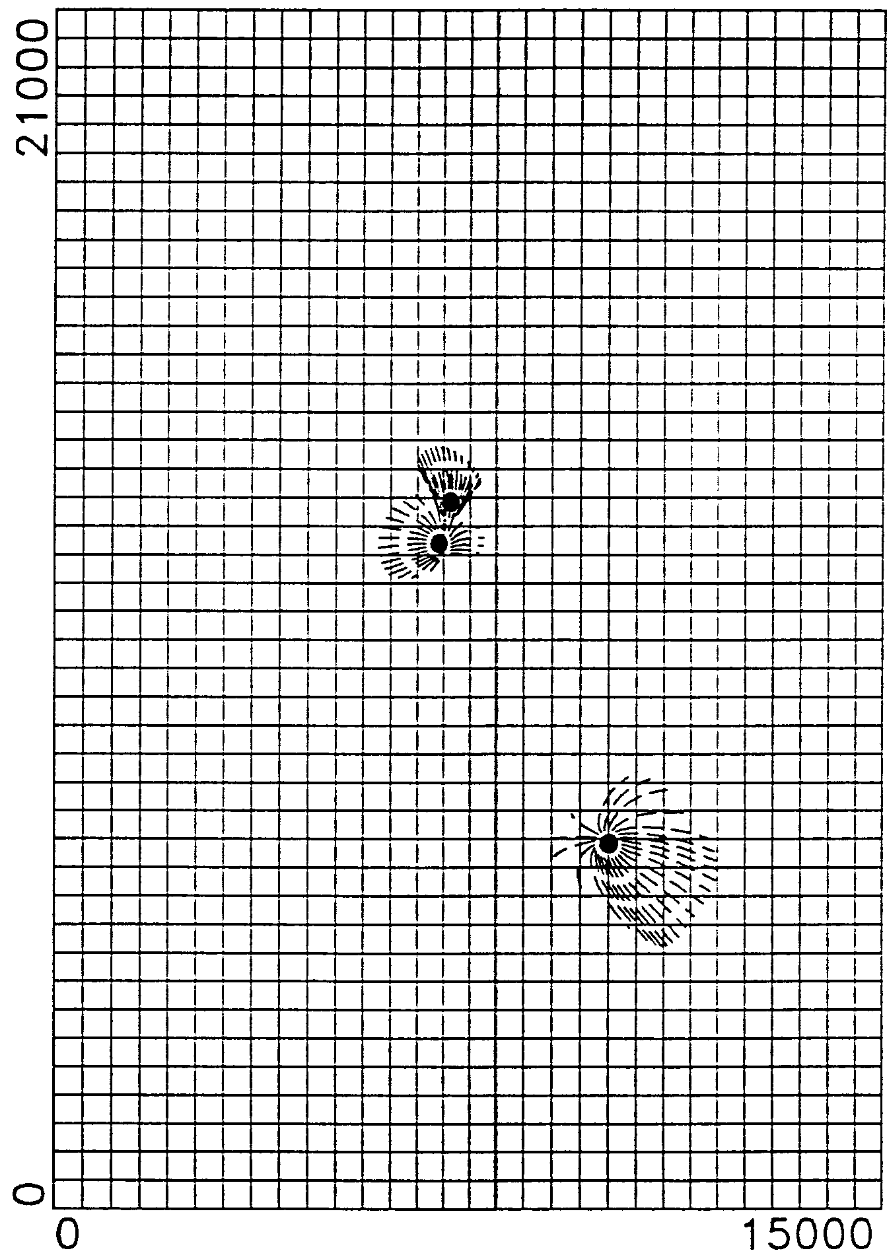


Figure 19. One year traveltime capture zones of NC-1, NC-2, and NC-4 based on best-estimate hydraulic parameter values.(Scales in feet.)

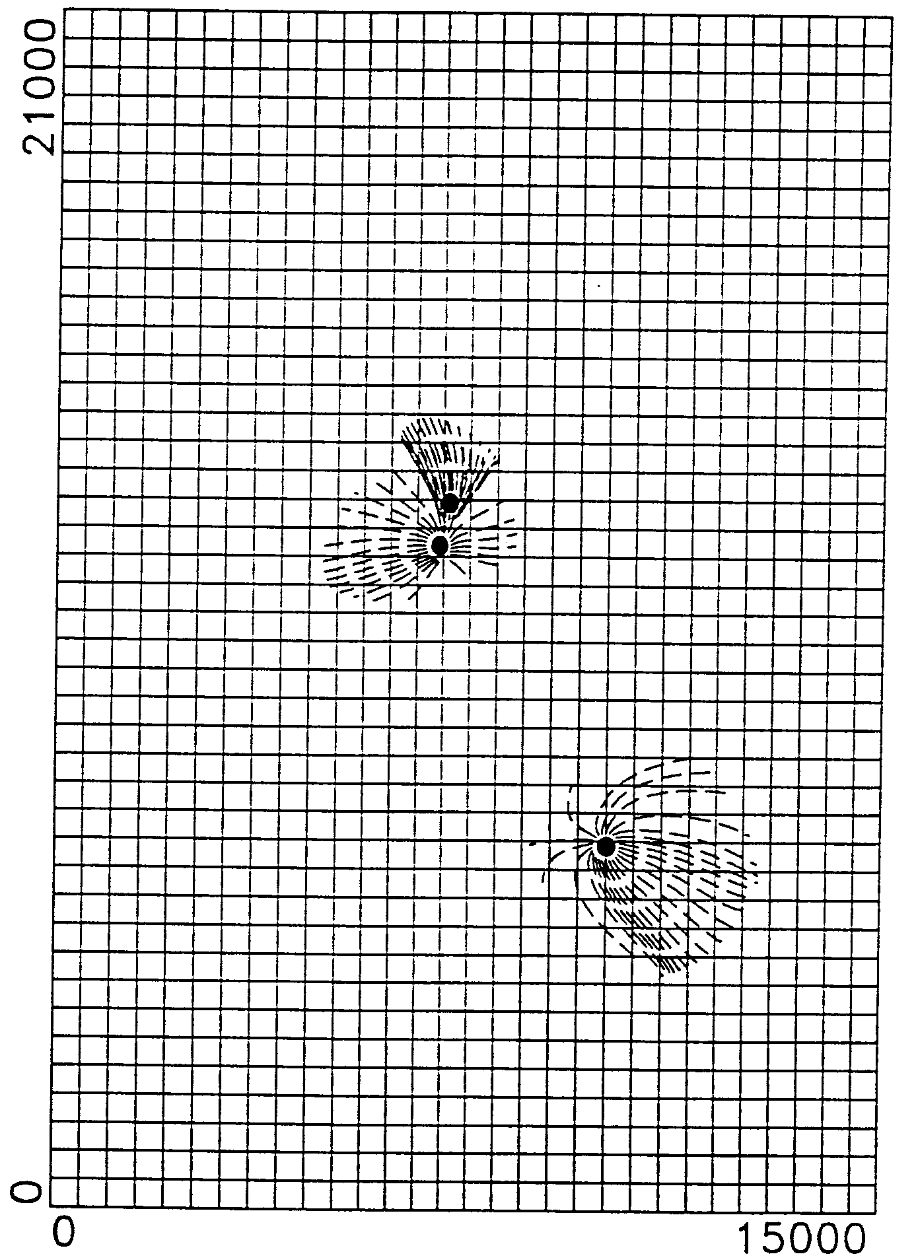


Figure 20. Two year traveltime capture zones of NC-1, NC-2, and NC-4 based on best-estimate hydraulic parameters values.(Scales in feet.)

Table 3

Areas of 1-Year Capture Zones Computed
Using Best-Estimate Parameter Values

1-YEAR CAPTURE AREA (Acres)

NC-1	NC-2	NC-4
23	51	135

calculates the area of the 36 triangular-shaped segments formed between the well and the loci of flowpath endpoints surrounding the well. Appendix C shows a listing of this program.

The shapes of the capture zones in both figures tend to be circular to slightly elliptical. Capture zones of NC-1 and NC-4 are elongated in a north-to-south trend, whereas the capture zone of NC-2 is elongated in a west-to-east trend. At NC-1 the capture zone extends predominantly up valley and up hydraulic gradient because of well interference with the greater pumping at NC-2. The capture zone of NC-4 predominantly spreads in an easterly direction because of the steeper hydraulic gradient to the east (see Figure 11).

Stochastic Approach

Uncertainty in describing ground-water flow systems commonly is attributed to natural variability in the geologic materials comprising the flow system, variability in hydraulic properties, and variability in the quality of the methods used to measure these properties (El-Kadi, 1984). Uncertainty due to the latter factor also can be attributed to human error. Hydraulic properties of geologic materials involve a degree of uncertainty that is better addressed using statistical assessments. An intrinsic uncertainty is derived from the variability of natural properties or processes in time and/or space (Dettinger and Wilson, 1981). Available field data commonly are not adequate to assess the small-scale heterogeneities that exist in most geologic materials. El-Kadi (1984) stated that either a deterministic or a stochastic approach can be used to study the problem of variability. When variability in space, spatial variability, is crucial, as in determining traveltime-related capture zones, a stochastic approach may be more appropriate.

In a stochastic approach, estimates of parameters are used instead of actual parameter values (El-Kadi, 1984). The parameters incorporated in the stochastic analysis of traveltime-related capture zones at the North Canton wellfields are hydraulic conductivity and porosity. The spatial heterogeneity of these parameters can be described only partially by deterministic approaches. The variability of hydraulic conductivity and porosity data are best represented by statistical measures that describe the variance or fluctuation about a mean value.

Porosity of geologic materials is known to be normally distributed, whereas hydraulic conductivity is known to be lognormally distributed (Freeze and Cherry, 1979, p. 31). The variability of hydraulic conductivity is thus reported as the standard deviation of the natural logarithm of the hydraulic conductivity (Hagley, 1988). Hagley (1988) summarized the findings from several statistical studies on the hydraulic conductivity of sandy materials (some of them glacially derived), reported as the standard deviation of the natural logarithm. The hydraulic parameters used to characterize the Massillon Sandstone were obtained by generating independent random values of hydraulic conductivity and porosity through the use of the International Mathematical and Statistical Library (IMSL) computer subroutines (IMSL, 1987). IMSL is a program library composed of FORTRAN subroutines which were used to generate random sets of values for hydraulic conductivity and porosity. IMSL transformed the randomly-generated uniform values into standard normal random values with a mean of 0 and a standard deviation of 1. The normal random values then were converted to represent the data describing the Massillon Sandstone aquifer based on the best-estimate values of hydraulic conductivity equal to 49 ft/d and porosity equal to 25 percent. The 100 independently generated random values of hydraulic conductivity and porosity were ordered to induce a correlation in pairs of hydraulic conductivity and porosity that is consistent with the correlation observed in the literature, as shown on Figure 21.

Figure 22a is a histogram of the random sample of 100 porosity values. The population from which the sample was generated has a normal distribution with a mean of 24.9 percent and a standard deviation of 3.9. Figure 22b shows a histogram of the random sample of 100 hydraulic-conductivity values. The hydraulic conductivity distribution is skewed to the right with a mean of 64.1 ft/d and a standard deviation of 52.2. However, by taking the natural logarithm of each

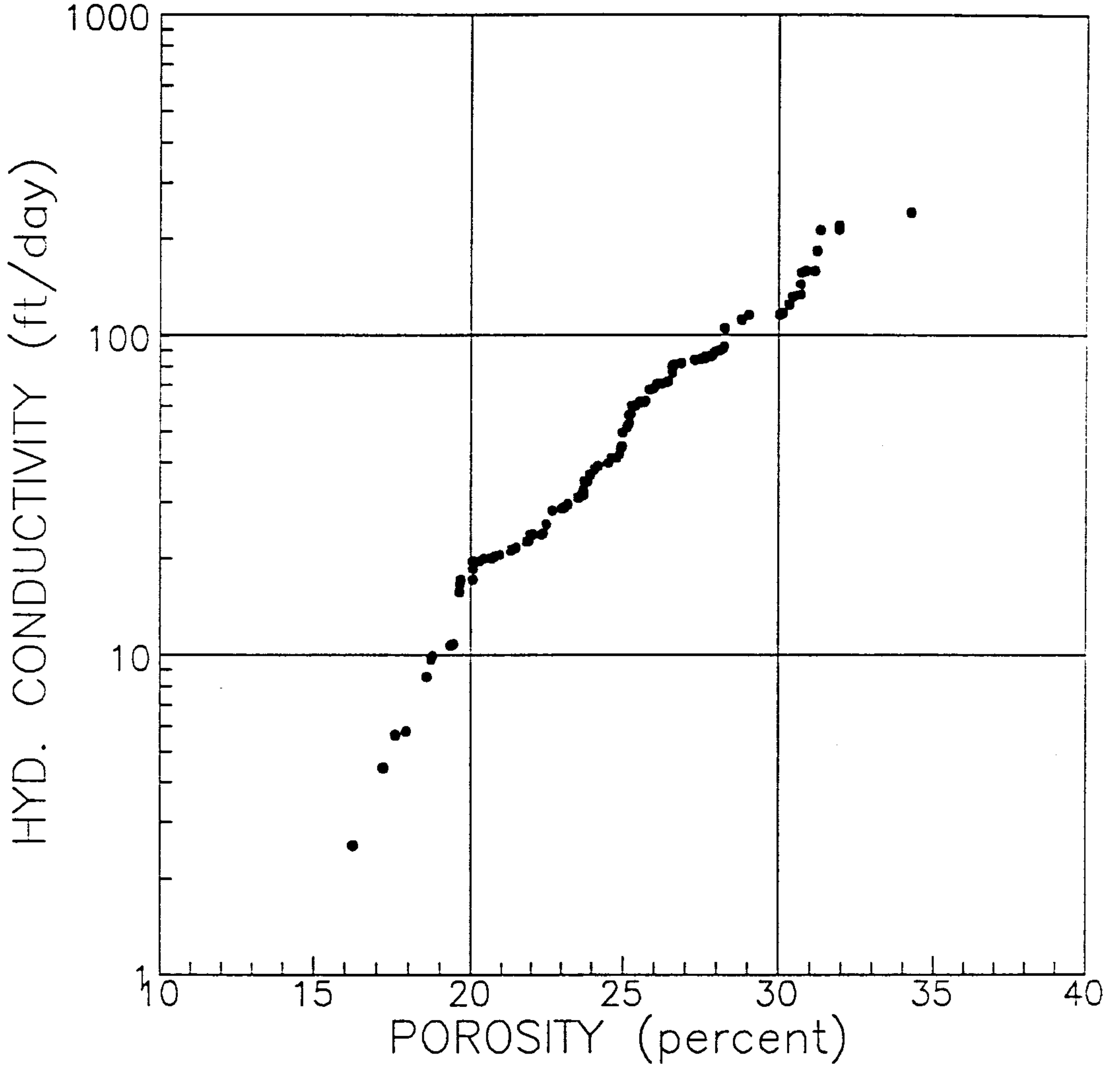


Figure 21. Plot of hydraulic conductivity versus porosity for the randomly-generated population.

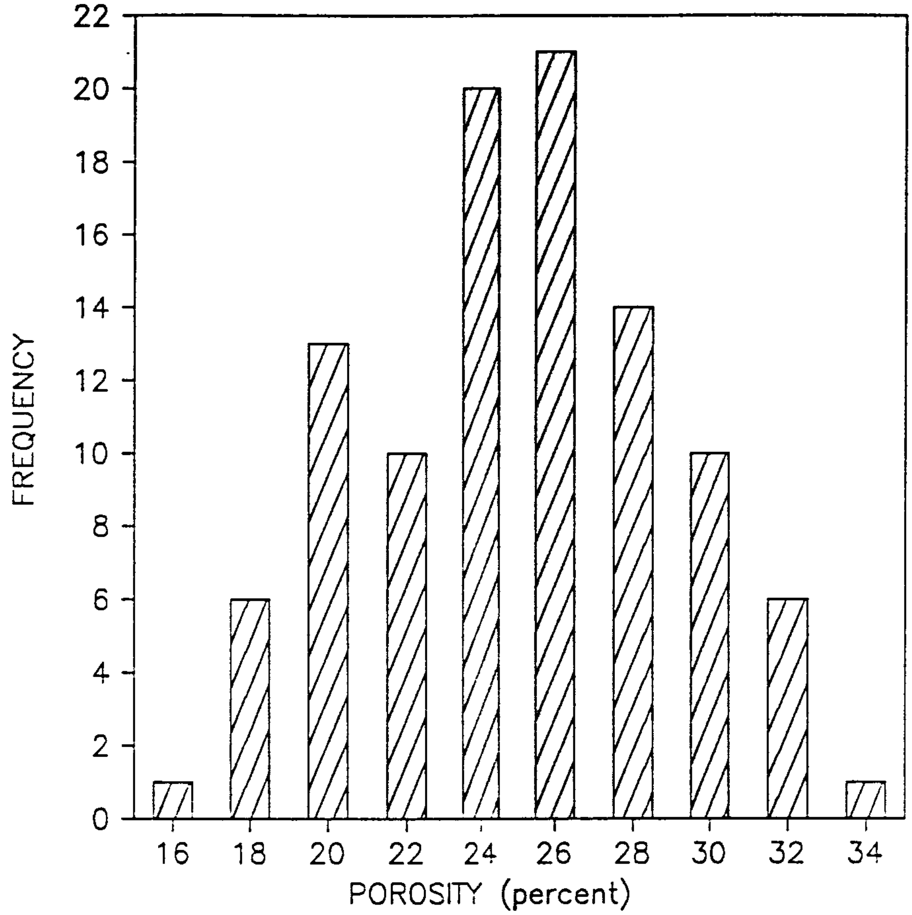


Figure 22a. Histogram of the random sample of 100 porosity values (μ = 24.9 and σ = 3.9).

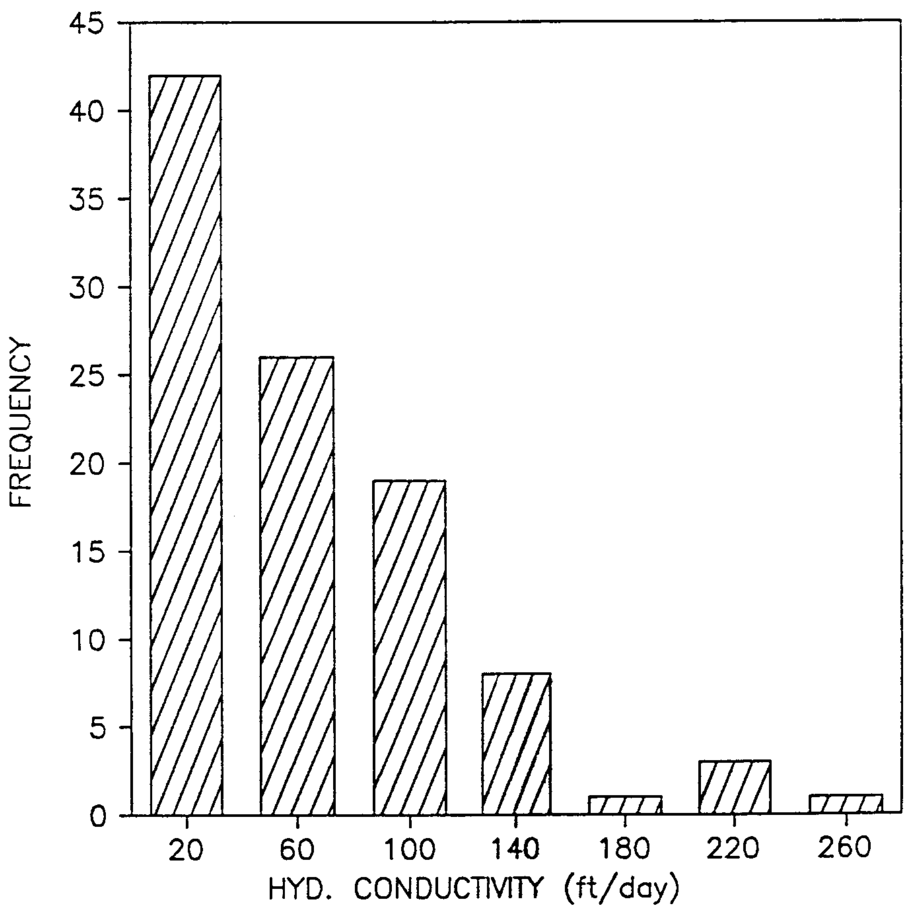


Figure 22b. Histogram of the random sample of 100 hydraulic conductivity values (μ = 64.1 and σ = 52.2).

hydraulic-conductivity value a normal distribution is created having a mean of 3.89 ft/d and a standard deviation of 1.0.

Monte-Carlo Simulations

Gomez-Hernandez and Gorelick (1989) described two common approaches that have been used in stochastic simulation of hydraulic conductivity: the Monte-Carlo approach and the analytical approach. In stochastic simulation, each parameter is represented as a random variable at a point in the flow domain. McLane (1990) stated "the Monte-Carlo approach uses repeated calculations based on a random sampling of the input parameters to generate a large number of model parameters to obtain a statistical estimate of the response of the system being studied."

The same procedures used to delineate the capture zones for the deterministic approach was used in the Monte-Carlo approach. However, instead of using only one set of best-estimate parameter values, 50 sets of parameter values were used to calculate 50 capture zones for each well. The input values were selected from a population of 100 random pairs of values of hydraulic conductivity and porosity by choosing every other paired set. (The even numbered observations from 1 to 100 were used because of time constraints that prevented calculation of 100 capture zones for each well.)

Each simulation began by using one of the 100 sets of parameter values in CAPZONE to compute predicted drawdowns at the intersections of a regularly-spaced rectangular grid and then subtracting computed drawdowns from regional hydraulic heads assigned at the same rectangular grid locations. The predicted hydraulic-head distribution computed in CAPZONE then was downloaded into GWPATH to calculate 36 1-year reverse flowpaths emanating from NC-1, NC-2, and NC-4. The loci of the 36 endpoints cimcumscribes the 1-year capture zone of the well.

For example, Figure 23 shows the predicted 1-year capture zones for the three bedrock wells from simulation 10 where the hydraulic conductivity and porosity values were 15.77 ft/d and 19.63 percent, respectively. Likewise, Figure 24 shows the predicted 1-year capture zones calculated using input values from simulation 90 with a hydraulic conductivity of 132.84 ft/d and a porosity of 30.5 percent. The shape of the capture zones in Figure 23 using lower values of hydraulic conductivity and porosity are more circular and centered closer to the well than those in Figure 24 which were computed using larger values of hydraulic conductivity and porosity. The capture zones for simulation 90 are more oblong and the flowpaths reach out in a preferential direction.

The next phase in each of the Monte-Carlo simulations was to describe the size, shape, and position of the capture zones. A FORTRAN program called AREA was written to compute capture-zone areas, shape factors, and center coordinates of the capture zone for each well. Appendix C contains a listing

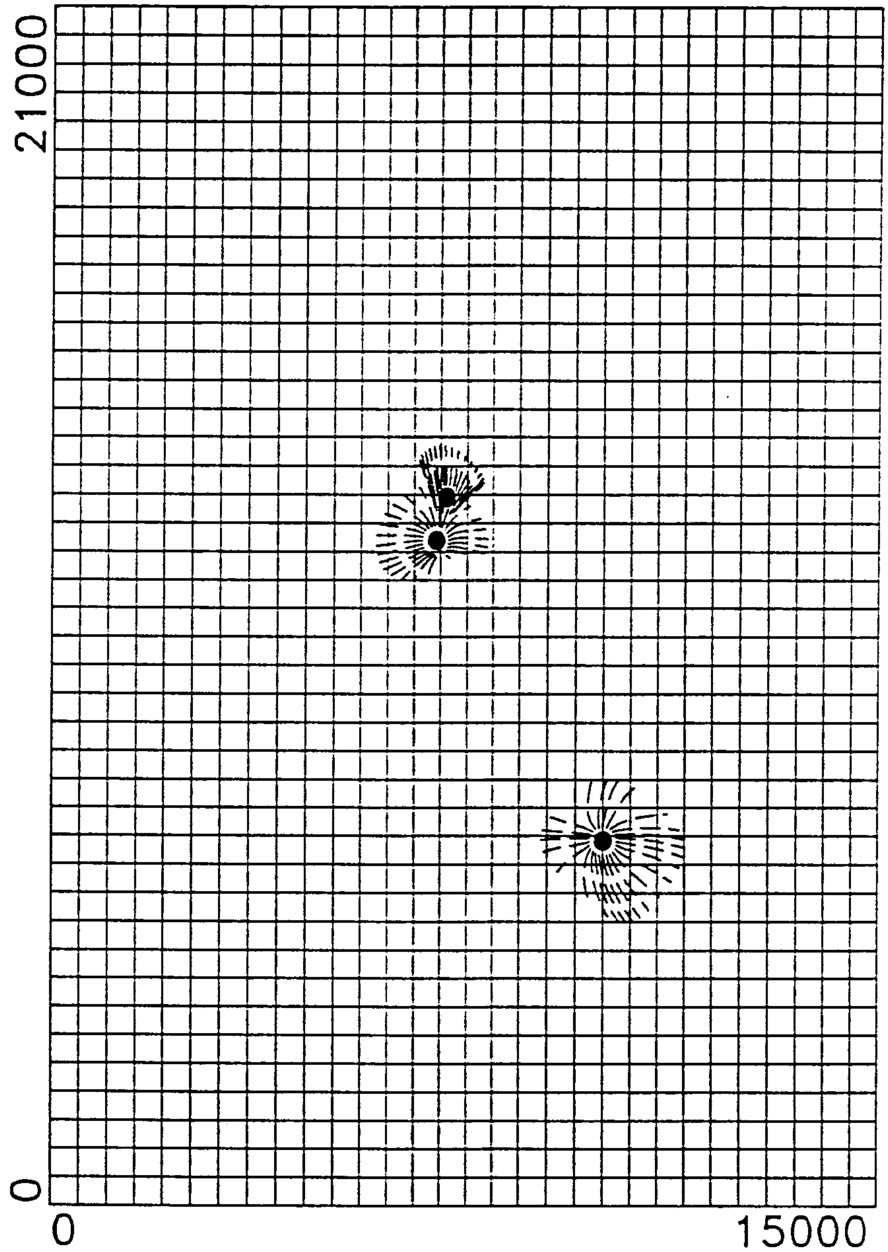


Figure 23. Predicted 1-year traveltime capture zones for the three bedrock wells from simulation 10 (K = 15.77 ft/d and n = 19.63 %).

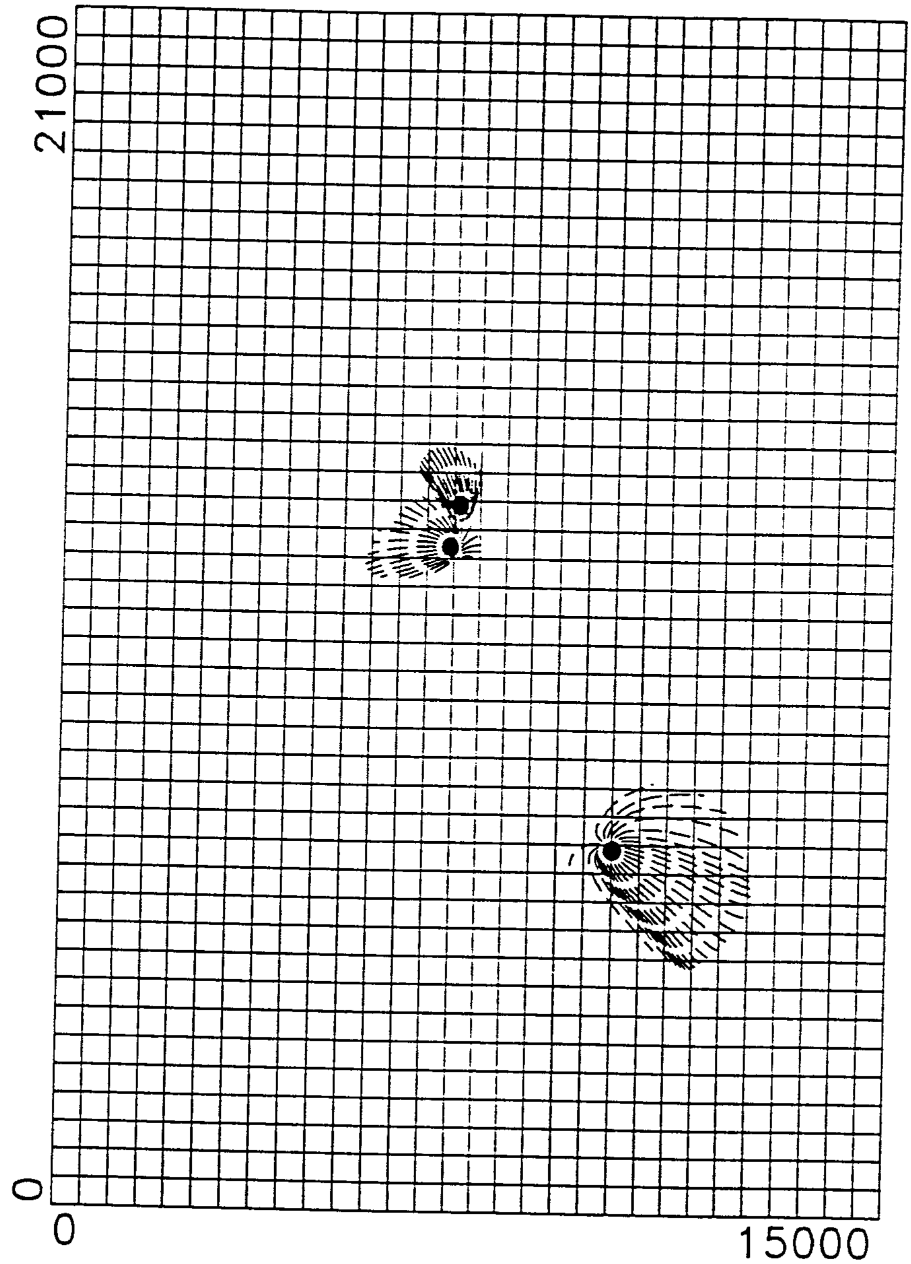


Figure 24. Predicted 1-year traveltime capture zones for the three bedrock wells from simulation 90 (K = 132.84 ft/d and n = 30.5 %).

of the FORTRAN code. The endpoints of each reverse flowpath computed in GWPATH were saved in a file that was downloaded into the AREA program. The coordinates of each well are entered and the area of the capture zone was found by summing the areas of the 36 triangle segments formed by drawing a line from the well to the coordinate of one flowpath endpoint, then across to connect with the next adjacent flowpath endpoint, and then from that endpoint to the well. The shape factor for each capture zone is found by determining values of the maximum y-coordinate, the minimum y-coordinate, the maximum x-coordinate, and the minimum x-coordinate. The vertical axis (y-axis) is designated as the length, whereas the horizontal axis (x-axis) is designated as the width. The ratio of length divided by width is the shape factor. If a capture zone has a shape factor greater than 1.0 it is longer in the length dimension and termed prolate. If a capture zone has a shape factor less than 1.0 it is longer in the width dimension and termed oblate.

The final factor used to describe the capture zones is used to define the position of the capture zone relative to its well. This is accomplished by determining the centroid coordinates of an equivalent rectangular capture zone with respect to a "local" cartesian grid surrounding the well. In the "local" coordinate system the location of the well is assigned values of X=0 and Y=0.

<u>Statistical Analysis of Monte-Carlo Results</u>

Table 4 is a summary of the Monte-Carlo statistics compiled for the 50 simulations for each of the three bedrock wells at North Canton. The shape factor (SF), area, and x-coordinate and y-coordinate of the capture-zone centroid (X-Cen and Y-Cen) for wells NC-1, NC-2, and NC-4 are shown for the 50 simulations which are labeled as observations 2 through 100. Various computer-generated histograms and graphs are used to show statistical summaries and trends of the simulation results.

Figures 25 through 30 are histograms showing the frequency of occurrence from the Monte-Carlo simulations of the capture-zone areas and shape factors. Figure 25 is a histogram of capture-zone areas computed for NC-1. The distribution is positively skewed toward larger capture-zone areas. The most frequently occurring capture-zone area is in the range having a midpoint of 24 acres (± 1 acre). Twenty-three capture zones fall within this range. The histogram of shape factors for NC-1 shown in Figure 26 is bimodal. The most frequently occurring shape factors are one with a midpoint of 0.50 (± 0.01) and the other with a midpoint of 0.56 (± 0.01). Twelve capture zones occur in each of these ranges. The shape of all the capture zones for NC-1 is oblate.

The histogram of capture-zone areas for NC-2 is shown in Figure 27. The distribution also is positively skewed. The greatest number of capture zones, 25, occurs within the range

Table 4

Monte-Carlo Summary Statistics

OBS	ln K	K (ft/d)	n (%)	T gpd/ft	Well 1 SF	Well 1 Area	Well 1 X-Cen	Well 1 Y-Cen	Well 2 SF	Well 2 Area	Well 2 X-Cen	Well 2 Y-Cen	Well 4 SF	Well 4 Area	Well 4 X-Cen	Well 4 Y-Cen
2	1.4929	4.45	17.21	3029	.6	22	145	546	.82	57.6	-29	131	1	86.5	59	-20
4	1.75613	5.79	17.93	3941	.6	21.8	139	553	.81	56.3	-35	129	1	87.4	74	-30
6	2.27624	9.74	18.72	6630	.58	22.9	127	586	.8	57.4	-52	133	1	94.9	125	-58
8	2.37024	10.7	19.34	7283	.58	23.3	124	596	.8	58.4	-56	135	1	97.4	138	-65
10	2.75811	15.77	19.63	10734	.57	23.6	104	617	.79	57.7	-75	139	1	104	196	-99
12	2.84141	17.14	19.67	11667	.57	24	99	626	.79	58.5	-81	141	1	107	214	-110
14	2.92101	18.56	20.06	12633	.56	24.5	95	636	.79	59.2	-86	143	1	110.5	232	-122
16	2.97859	19.66	20.28	13382	.56	24.8	91	643	.79	59.8	-91	145	1	112.9	247	-122
18	2.99972	20.08	20.67	13668	.57	23.4	86	623	.78	55.7	-91	140	1	108	241	-128
20	3.02723	20.64	20.93	14049	.57	23.5	84	626	.78	56	-93	141	1	109	246	-133
22	3.07731	21.7	21.49	14771	.56	23.8	80	633	.78	56.4	-97	142	1	111	261	-142
24	3.12676	22.8	21.92	15520	.57	22.6	73	617	.77	53	-100	138	1	107.8	264	-143
26	3.1722	23.86	22.05	16241	.57	22.9	70	622	.77	53.4	-104	139	1	109.8	277	-152
28	3.18221	24.1	22.41	16404	.57	22.9	69	624	.77	53.5	-105	140	1	110.3	280	-153
30	3.34357	28.32	22.7	19277	.56	22.4	53	624	.76	51.4	-118	137	1	112.4	317	-175
32	3.36867	29.04	23.11	19767	.56	22.6	51	627	.76	51.6	-120	138	1	114	325	-180
34	3.43624	31.07	23.57	21149	.57	21.7	43	615	.76	48.9	-126	134	1	111.7	336	-185
36	3.45663	31.71	23.73	21584	.56	21.8	41	618	.76	49.1	-128	134	1	112.7	343	-189
38	3.55191	34.88	23.77	23742	.56	22.3	31	632	.75	50	-139	138	1	117.8	378	-210
40	3.60032	36.61	23.94	24920	.56	22.6	26	639	.75	50.4	-145	141	1	121	397	-221
42	3.66612	39.1	24.19	26615	.55	23	18	649	.75	51.1	-154	144	1	125	424	-237
44	3.72256	41.37	24.63	28160	.56	22.1	11	637	.75	48.5	-160	139	1	122.5	434	-243
46	3.75279	42.64	24.89	29024	.55	22.3	7	642	.75	48.8	-164	141	1	124.5	448	-250
48	3.79436	44.45	24.93	30256	.55	22.5	1	649	.75	49.2	-170	143	1	127.1	467	-262
50	3.90399	49.6	24.99	33762	.54	23.3	-15	668	.74	50.5	-188	149	.99	134.5	516	-292
52	3.97255	53.12	25.2	36158	.54	23.8	-26	681	.74	51.3	-201	152	.99	139.3	548	-307
54	4.02553	56.01	25.2	38125	.53	24.2	-35	692	.74	52	-211	155	.99	143.1	572	-318
56	4.09484	60.03	25.3	40861	.53	24.8	-48	706	.73	52.9	-226	159	.99	148	605	-333
58	4.12326	61.76	25.53	42039	.53	23.7	-51	689	.73	50.1	-227	152	.99	144.1	605	-333
60	4.13373	62.41	25.71	42481	.53	23.8	-53	692	.73	50.2	-229	152	.99	145	610	-336
62	4.22523	68.39	25.99	46552	.53	24.6	-72	712	.72	51.5	-251	157	.98	151.2	655	-358
64	4.2576	70.64	26.23	48083	.52	24.9	-79	720	.72	52	-259	159	.98	153.5	671	-366
66	4.27472	71.86	26.45	48914	.52	25	-83	724	.72	52.3	-264	160	.97	155	680	-370
68	4.37802	79.68	26.59	54237	.52	24.7	-103	727	.72	50.9	-285	157	.97	156	719	-391
70	4.39482	81.03	26.63	55155	.52	24.9	-107	731	.71	51.1	-290	158	.96	157	727	-396
72	4.43189	84.09	27.3	57238	.52	25.3	-116	741	.71	51.8	-302	160	.96	160	746	-404
74	4.44441	85.15	27.63	57960	.52	24.1	-114	721	.71	49	-297	153	.96	155	740	-404
76	4.46026	86.51	27.84	58886	.52	24.3	-118	726	.71	46.9	-295	147	.96	156	748	-406
78	4.48153	88.37	27.91	60152	.52	24.9	-126	738	.71	50.5	-311	156	.96	159	763	-408
80	4.50048	90.06	28.09	61302	.52	24.7	-129	737	.71	49.9	-315	155	.96	159	769	-409
82	4.52851	92.62	28.23	63045	.52	25	-137	745	.71	50.5	-325	157	.96	161	784	-411
84	4.71761	111.9	28.8	76168	.5	27.4	-198	809	.69	54.7	-403	166	.95	172	891	-434
86	4.75428	116.08	30.04	79013	.51	25.2	-194	770	.69	49.5	-391	154	.96	165	887	-437
88	4.82855	125.03	30.34	85105	.5	26.2	-221	798	.68	51.2	-427	157	.95	168	936	-451
90	4.88915	132.84	30.5	90422	.51	25.7	-235	796	.68	50	-442	153	.95	167	966	-462
92	4.97314	144.48	30.7	98345	.5	26.9	-270	831	.67	52.3	-491	157	.96	170	1039	-485
94	5.06878	158.98	30.87	108215	.49	28.4	-315	874	.65	55.7	-555	159	.98	169	1156	-512
96	5.21292	183.63	31.23	124993	.48	31	-395	949	.63	62	-679	156	1.2	175	1486	-475
98	5.36742	214.31	31.92	145877	.48	32.7	-480	1013	.6	67.2	-814	144	1.5	190	1860	-496
100	5.49075	242.44	34.26	165024	.49	32.3	-535	1032	.59	67.6	-891	134	1.6	196	2009	-532

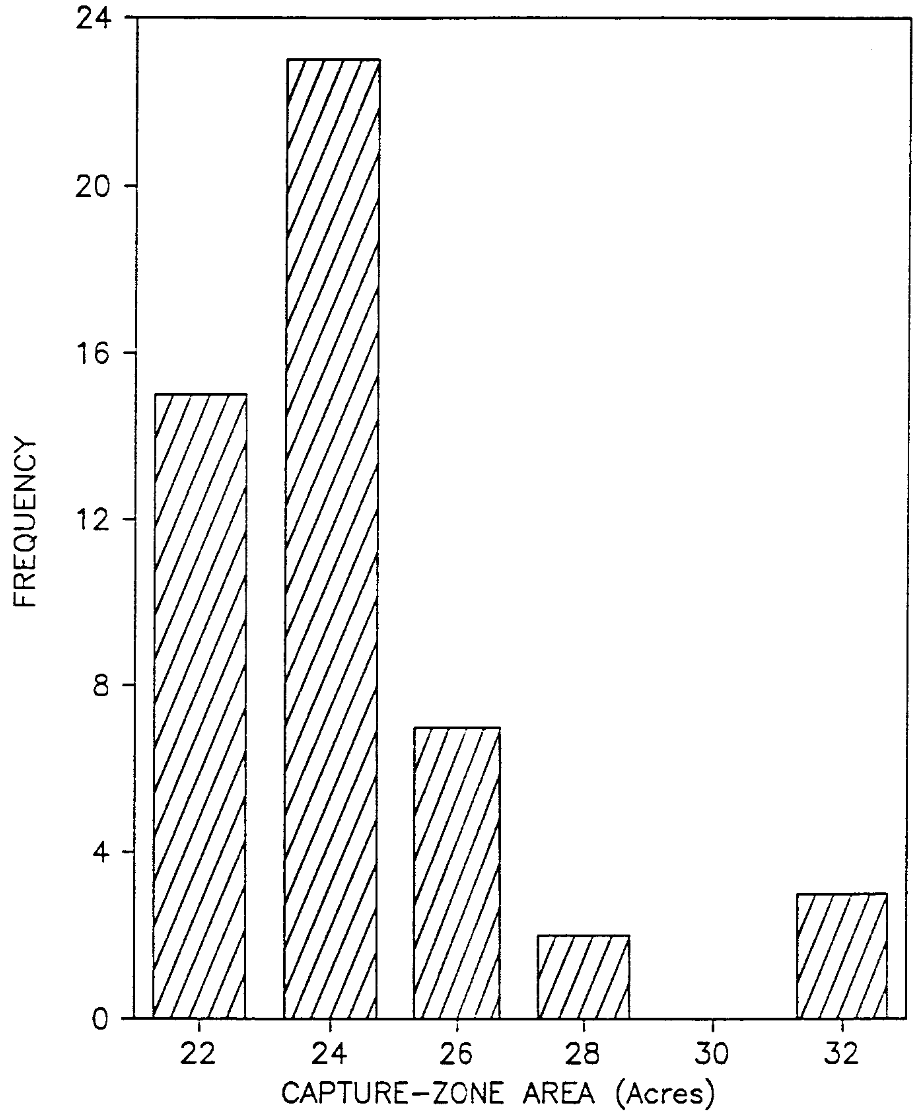


Figure 25. Histogram oi capture-zone areas computed for NC-1.

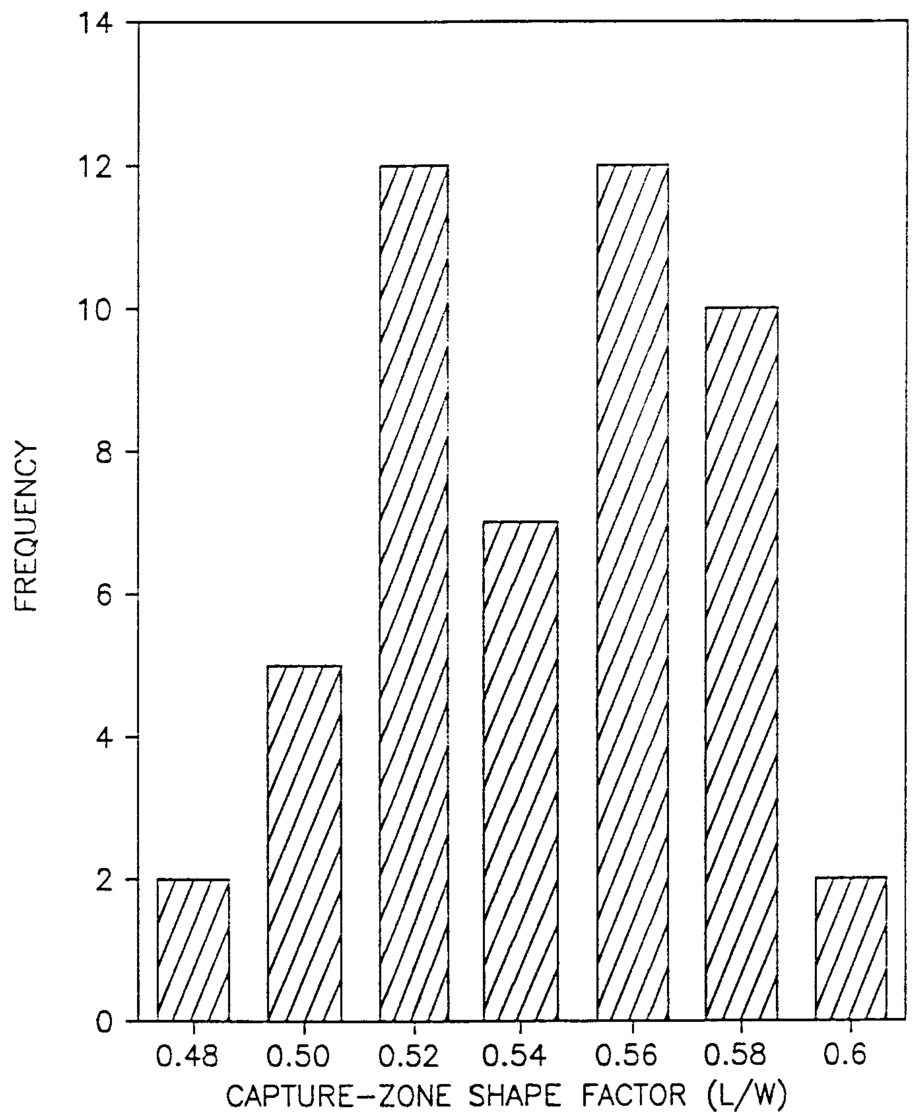


Figure 26. Histogram of shape factors computed for NC-1.

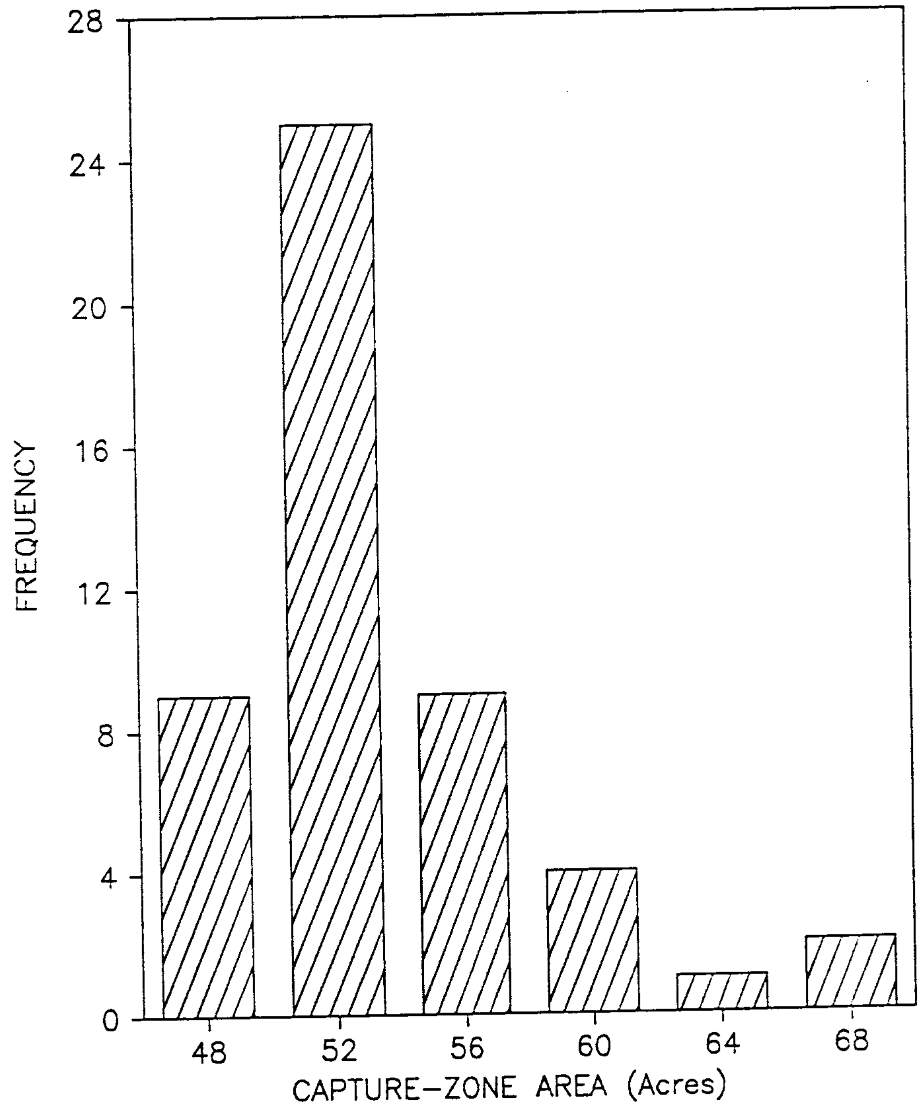


Figure 27. Histogram of capture-zone areas computed for NC-2.

having a midpoint of 52 acres (± 2 acres). The histogram of shape factors for NC-2 as shown in Figure 28 is skewed toward the lower, more oblate shape factors. The most frequently occurring range of shape factors, 16 of 50, has a midpoint of 0.76 (± 0.02). The shape factors are all oblate.

Figure 29, the histogram of capture-zone areas for NC-4, is bimodal. The two most frequently occurring ranges contain 14 of the 50 computed capture zones with a midpoint value of 120 acres (± 10 acres) and 15 capture zones with a midpoint value of 160 acres (± 10 acres). The histogram of shape factors for NC-4 shown in Figure 30 is extremely positively skewed with 47 of 50 capture zones having a shape factor in the range from 0.95 to 1.05. The shape of the capture zones for NC-4 subtly shifts from having a shape factor of one in which length equals width, to less than one in which the shape is slightly oblate and then greater than 1 in which the shape is slightly prolate.

Trends in the position of the capture-zone centroids for the three wells with respect to increasing hydraulic conductivity and porosity are shown in Figures 31 through 33. Figure 31 shows the position of the capture-zone centroid relative to the location of NC-1. The centroid tends to shift from being in the first quadrant to the second quadrant (from northeast to northwest of the well) with increasing values of hydraulic conductivity and porosity. Figure 32 depicts a trend in the position of the capture-zone centroids for NC-2

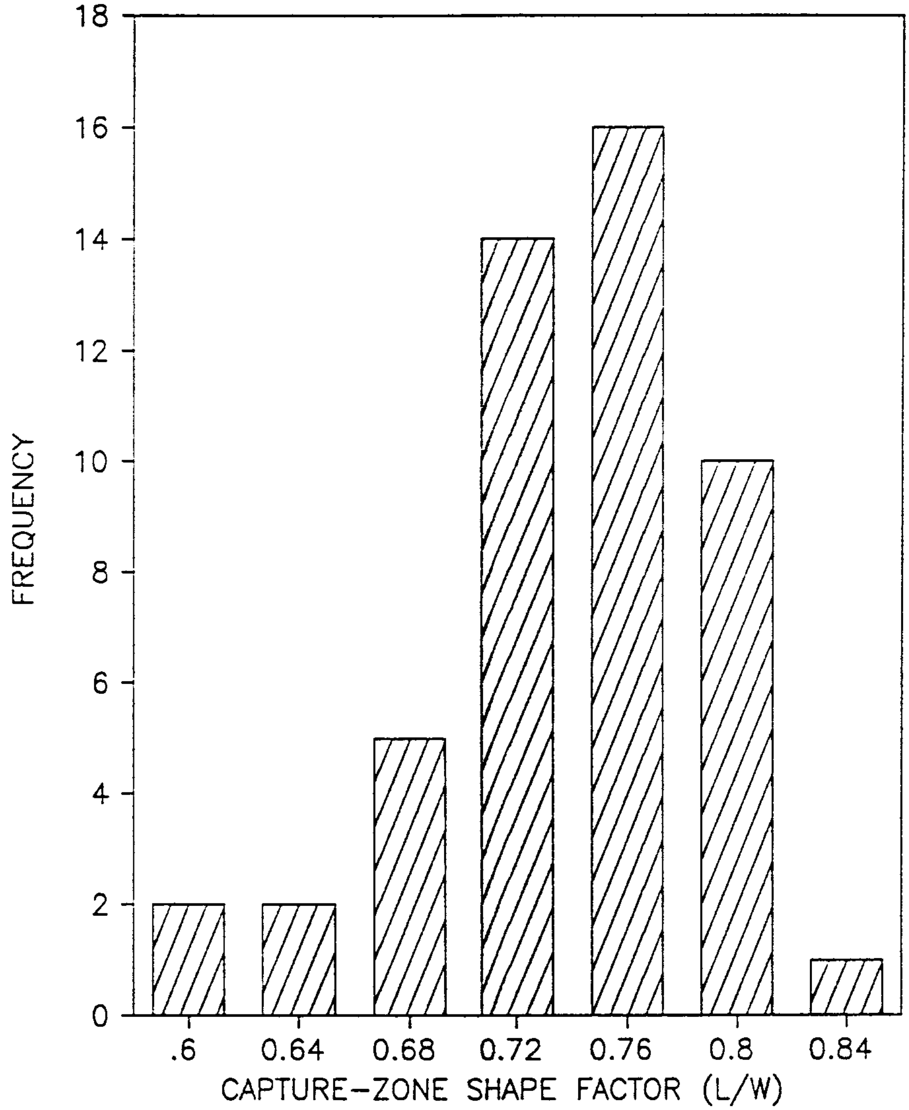


Figure 28. Histogram of shape factors computed for NC-2.

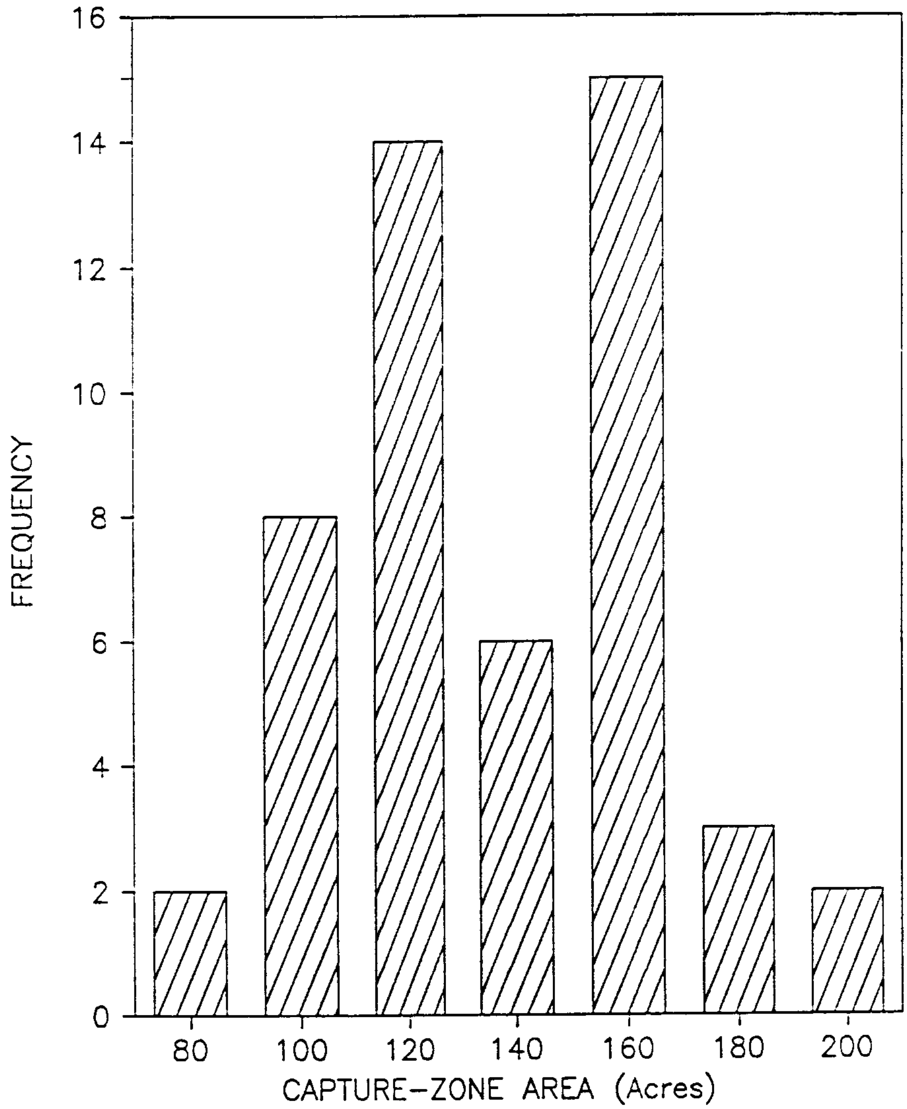


Figure 29. Histogram of capture-zone areas computed for NC-4.

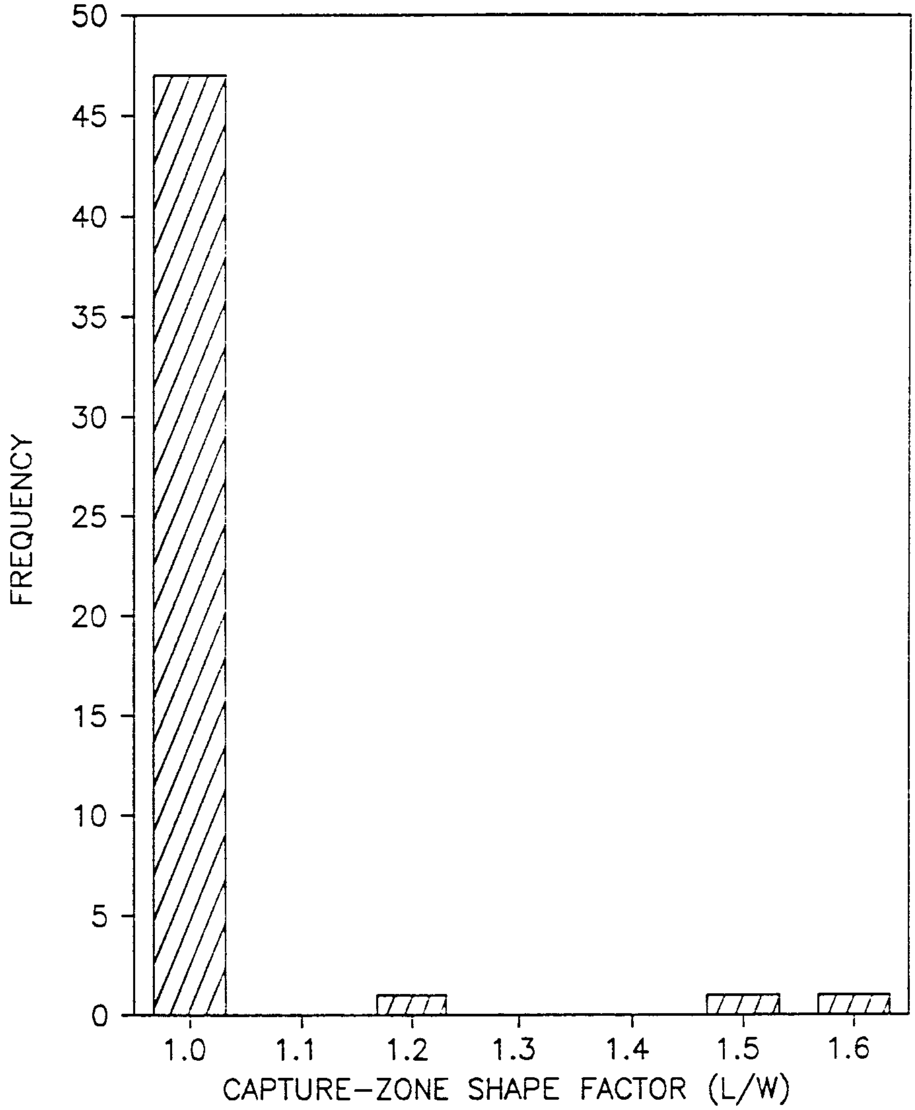


Figure 30. Histogram of shape factors computed for NC-4.

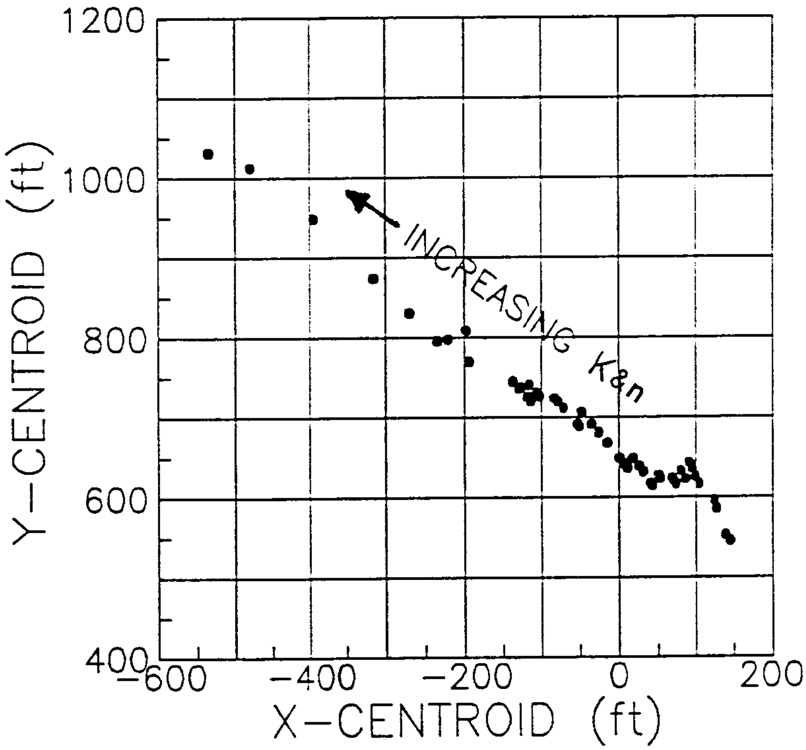


Figure 31. Position of the capture-zone centroid relative to the location of NC-1.

that is not as definitive as the trend for NC-1. The centroids are all located in the second quadrant (northwest of the well) and tend to shift in a counterclockwise direction beginning at a position close to the origin and then moving in a circular path near the x-axis at lower negative x-coordinate values as hydraulic conductivity and porosity increase. Figure 33 shows that the position of the capture-zone centroids for NC-4 are entirely in the fourth quadrant (southeast of the well). The centroids shift to the right in the fourth quadrant to lower "local" y-coordinate values and higher "local" x-coordinate values with increasing values of hydraulic conductivity and porosity.

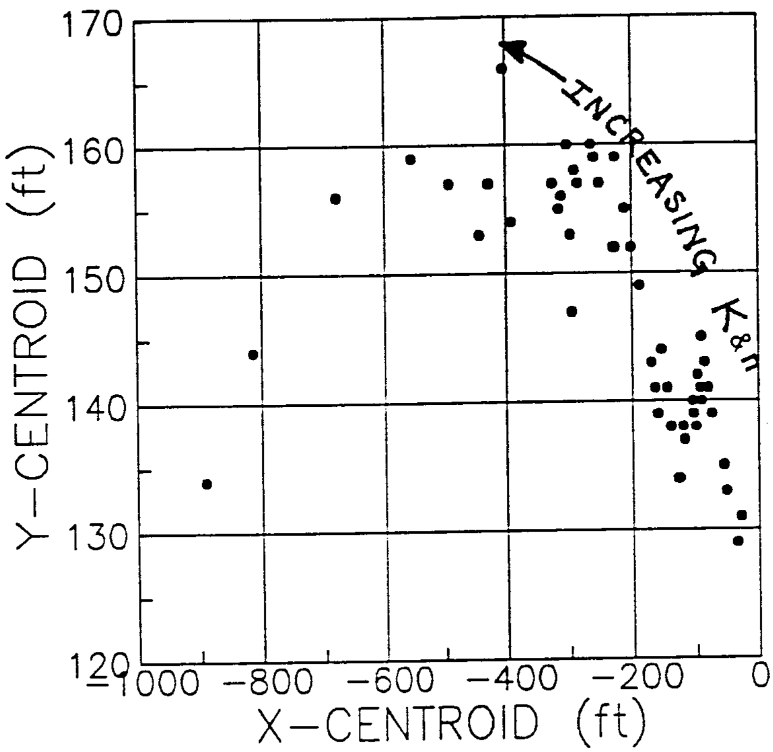


Figure 32. Position of the capture-zone centroid relative to the location of NC-2.

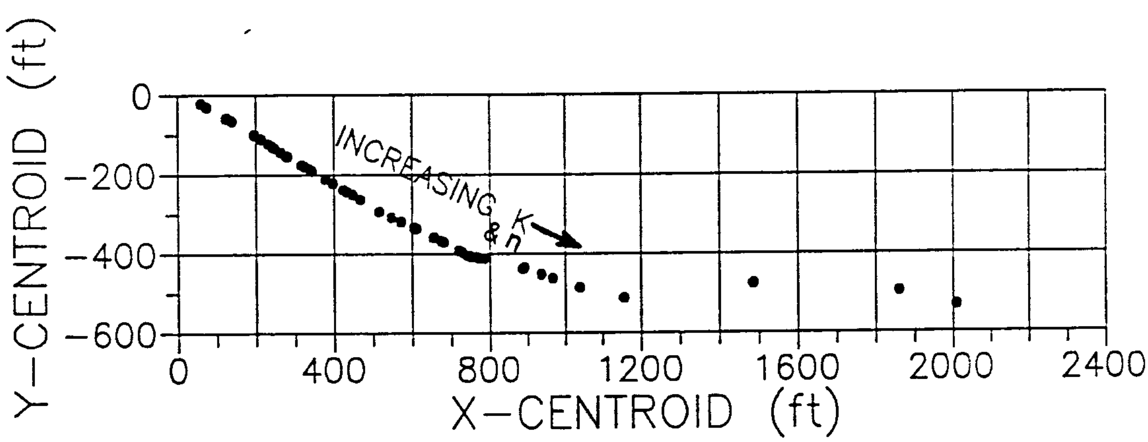


Figure 33. Position of the capture-zone centroid relative to the location of NC-4.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Ground-water flow at the North Canton wellfields is characterized by an unconfined glacial-drift aquifer located in a buried-glacial valley and an underlying sandstone aquifer which is confined by and intervening shale unit. The upper aquifer consists of surficial glacial-drift deposits averaging about 60 ft in thickness. The lower aquifer is a leaky-confined aquifer consisting of 90 to 100 ft of the Massillon Sandstone that is overlain by 20 to 45 ft of shale. Three of the five municipal wells (NC-1, NC-2, and NC-4) operated by the City of North Canton are completed in the Massillon Sandstone. The other two municipal wells are completed in the surficial glacial-drift aquifer. NC-1 is contaminated by trichloroethylene and is no longer pumped for municipal use. Together, the remaining other four wells produce about 3.2 million gallons per day and serve nearly 6,000 users.

Water levels were measured on two occasions (May and October 1989) in a network of domestic and industrial wells in the vicinity of the wellfields. An aquifer test was performed in September 1989 at the Freedom Avenue Wellfield to determine values for the hydraulic parameters of the Massillon Sandstone aquifer. The best-estimate values from the analysis of these data are a horizontal hydraulic conductivity of 49 ft/d, a transmissivity of 4,460 ft2/d, a storativity of 0.00005, and a vertical hydraulic conductivity of the confining layer of 0.012 ft/d.

The best-estimate values and the potentiometric surface data were used to compute 1-year capture zones for the three bedrock wells. The results indicate that the capture-zone areas using the best-estimate values are approximately 23.3 acres for NC-1, 50.5 acres for NC-2, and 135 acres for NC-4. The shape factor (length/width) for the three capture zones is less than 1.0 indicating that the capture zones are oblate to varying degrees.

The capture-zone shape factor of NC-1 is 0.54. Particle-tracking analysis indicates that the capture zone of NC-1 spreads in a fan shape up the valley. The shape factor of NC-2 capture zone is 0.74 and is elongated in a west-to-east direction with flowpaths extending predominantly to the west. The capture zone of NC-4 is nearly equidimensional having a shape factor of 0.99. Particle-tracking analysis shows that the majority of flowpaths spread out in east-to-southeasterly direction.

One of the likely sources of ground-water contamination in the study area is a truckstop located at an offramp of I-77. Particle-tracking analysis showed that a flowpath in the Massillon Sandstone aquifer beneath the truckstop would reach NC-2 in a traveltime of about 5 years.

Because the size, shape, and position of capture zones are dependent on the values of hydraulic parameters used to compute drawdowns and to determine flowpaths, a Monte-Carlo stochastic approach was used to assess the effect of parameter uncertainty on the delineation of capture zones. Fifty trials for each of the three bedrock wells were simulated using randomly-generated samples of hydraulic conductivity and porosity. Statistics were compiled using the results of each Monte-Carlo simulation to characterize the capture zones on the basis of their areas, shape factors, and centroid positions relative to the location of the well.

Conclusions

Figures 34 through 36 depict the relation between shape factor and hydraulic conductivity for NC-1, NC-2, and NC-4. Figure 34 shows that the capture zone of NC-1 becomes more oblate with increasing hydraulic conductivity and porosity. The same relation is seen in Figure 35 for the capture-zone shapes of NC-2. In Figure 36 the data for NC-4 show that shape factor is relatively independent of hydraulic-conductivity and porosity values, particularly for hydraulic conductivity values less than 45 ft/d. When the hydraulic conductivity is between 45 to 159 ft/d the capture zone is slightly oblate, whereas for hydraulic-conductivity values greater than 159 ft/d the capture zone is slightly prolate.

Figures 37 through 39 compare the change in capture-zone area for each well with values of hydraulic conductivity and porosity. Figures 37 and 38 are plots of capture-zone area

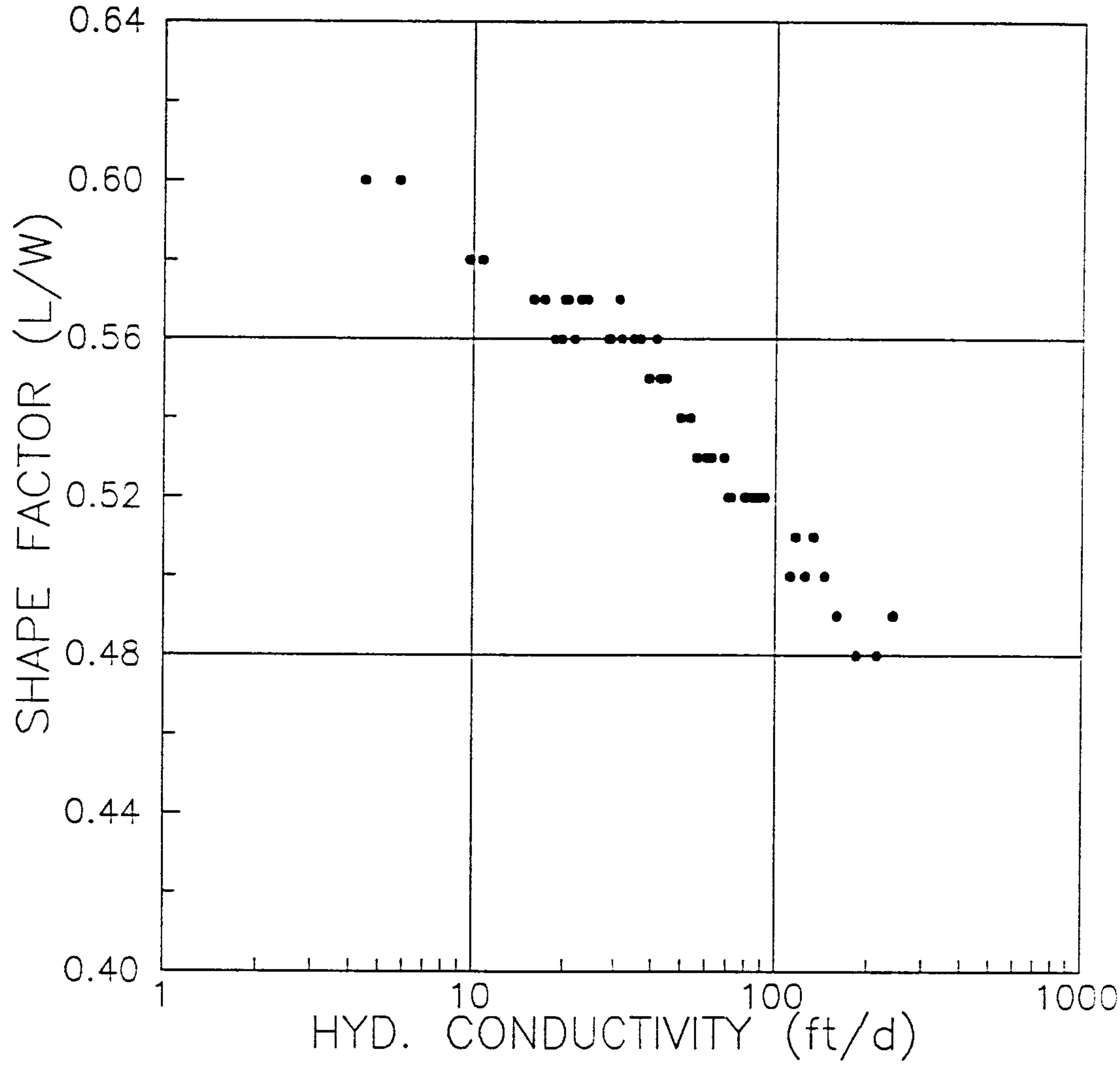


Figure 34. Capture-zone shape factor versus hydraulic conductivity at NC-1.

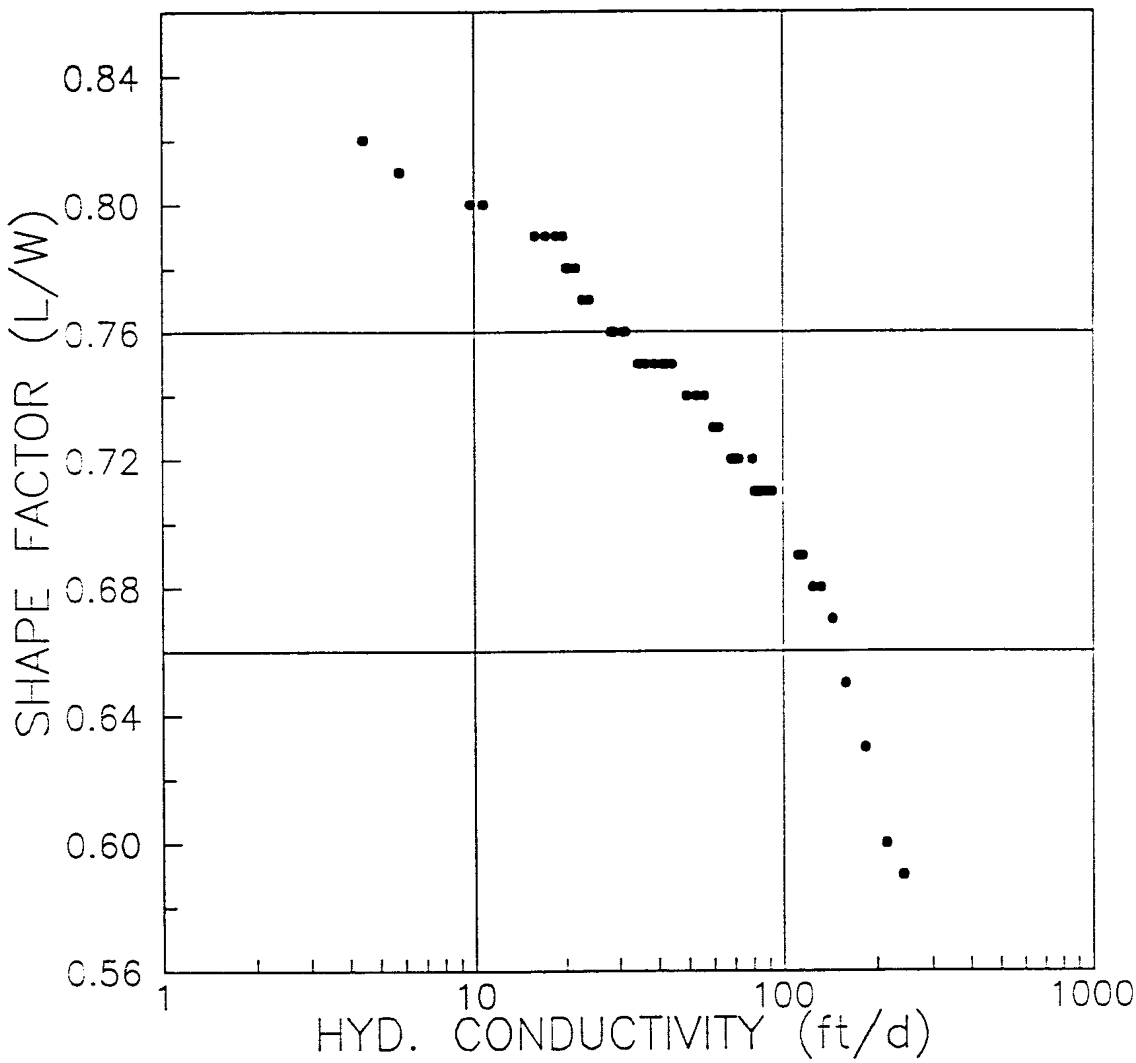


Figure 35. Capture-zone shape factor versus hydraulic conductivity at NC-2.

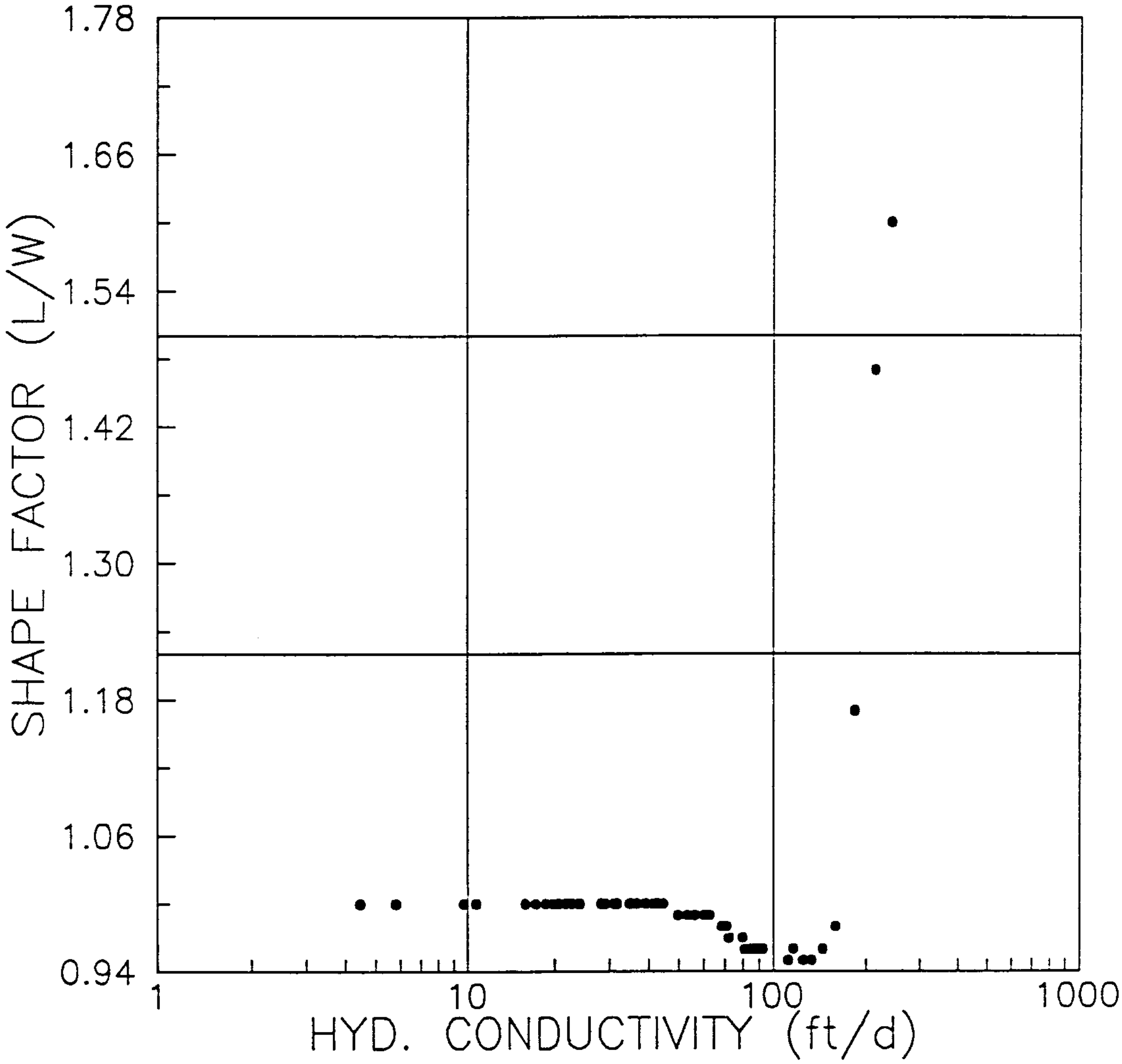


Figure 36. **Capture-zone shape factor versus hydraulic conductivity at NC-4.**

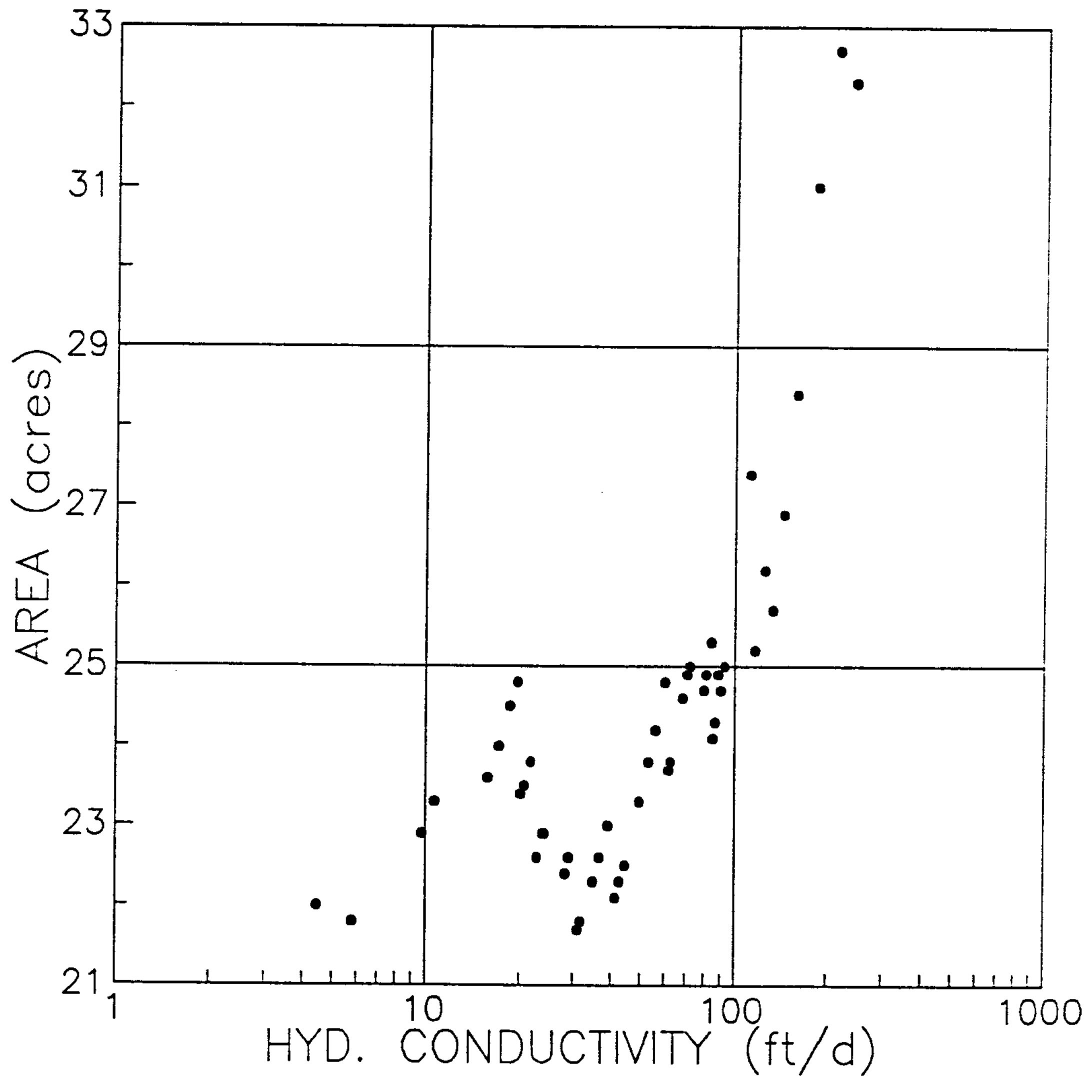


Figure 37. Change in capture-zone area with hydraulic conductivity at NC-1.

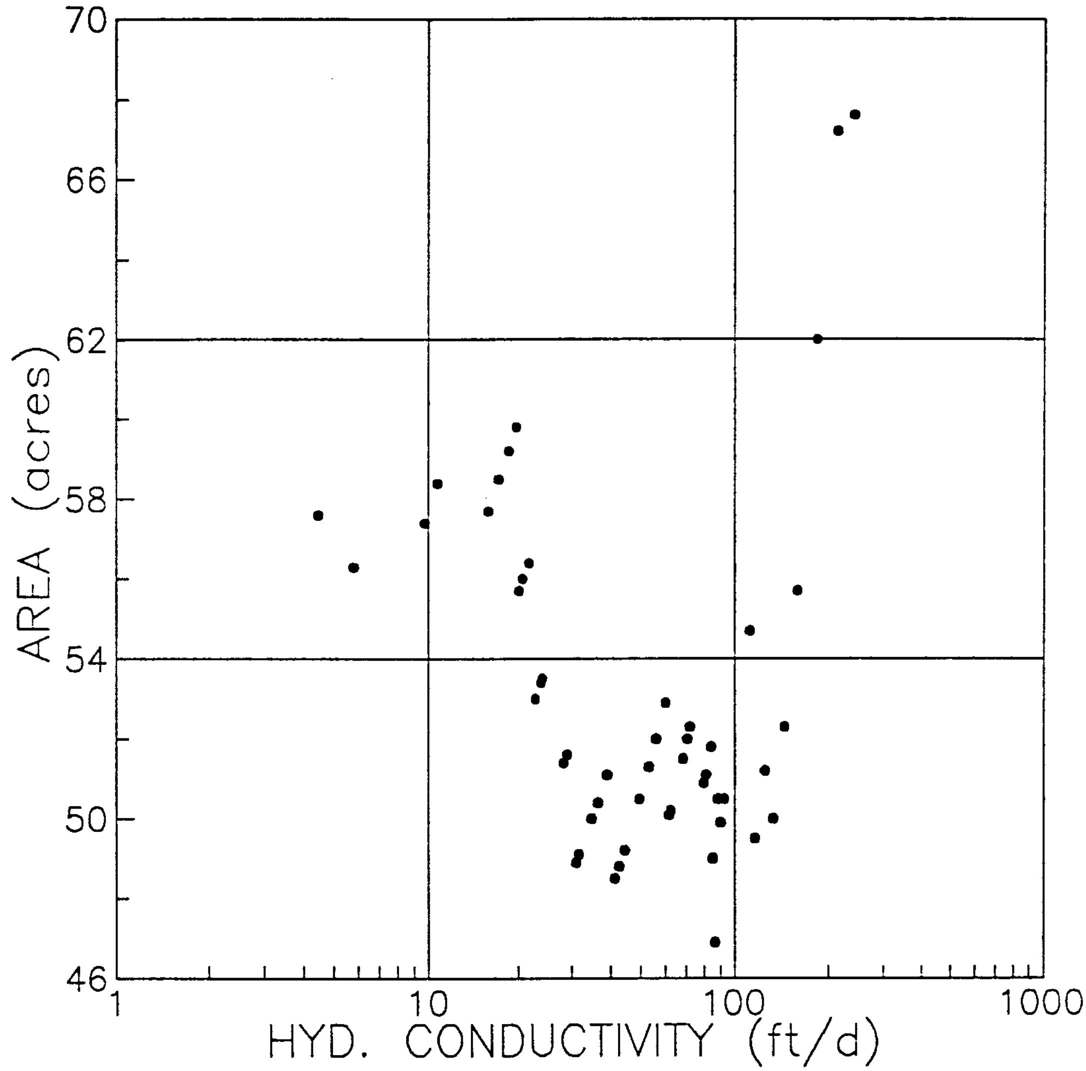
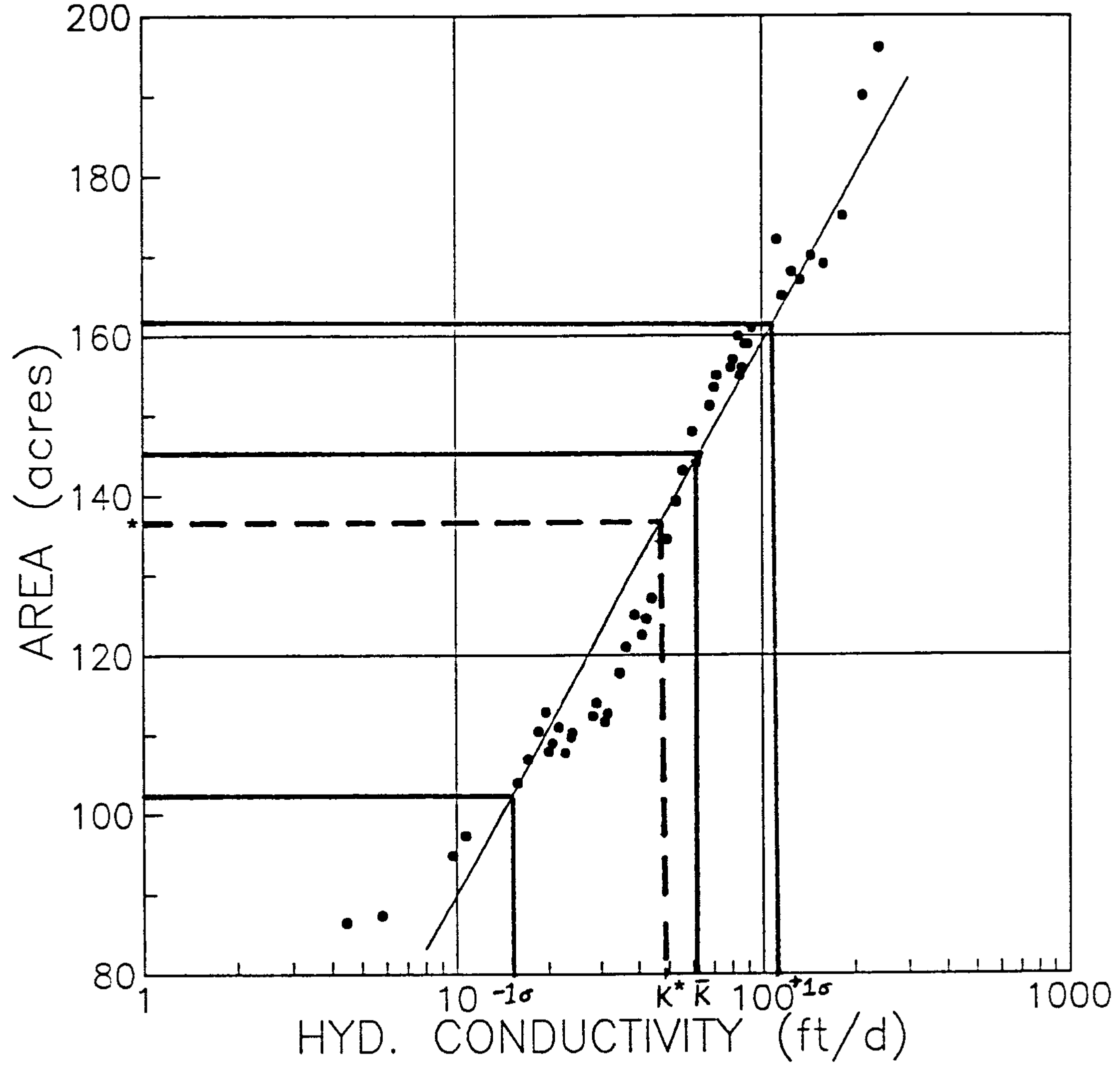


Figure 38. Change in capture-zone area with hydraulic conductivity at NC-2.

versus hydraulic conductivity for NC-1 and NC-2. In general, area increases with increasing hydraulic conductivity and porosity, however, the data points in both plots are too scattered to show any discernable relations. The inconsistent relations between area and increasing hydraulic conductivity and porosity can be attributed to well interference between NC-1 and NC-2 which are in close proximity to each other. A better relation between area versus hydraulic conductivity and porosity can be seen in Figure 39 which is a plot of the capture-zone data for NC-4. A best-fit line was computed such that $Y = 30.04 * \ln(X) + 20.78$, where Y equals capture-zone area (acres) and X equals hydraulic conductivity (ft/d). (Bias from the extreme values of hydraulic conductivity was not entered into the regression.) The area of the capture zone of NC-4 increases as the hydraulic conductivity and porosity values increase because the cone of depression steepens and spreads more laterally covering a larger area and enabling particles to travel a greater distance in a 1-year period.

In Figure 39 the best-estimate value of hydraulic conductivity (49 ft/d) and the mean hydraulic conductivity value of the random population data (62 ft/d) as well as plus and minus one standard deviation (σ) from the mean value are drawn to the best-fit line. The range of areas between $+1\sigma$ and -1σ indicates a difference of 60 acres in the predicted capture-zone area that could result if the hydraulic



K^* = Best-estimate hydraulic conductivity (49 ft/d)
$\bar{K}$ = Mean hydraulic conductivity of random sample (64.1 ft/d)

Figure 39. Change in capture-zone area with hydraulic conductivity at NC-4.

conductivity value used in the analyses were +1σ or -1σ from the mean. The predicted capture-zone area could range from 102 acres to 162 acres in size.

Comparison of the capture-zone area for each well based on the best-estimate (deterministic) values with the most probable area based on the Monte-Carlo method can be made using the histograms from Figures 25, 27, and 29 (Table 5). The area computed using the best-estimate values for NC-1 is approximately 23 acres which falls within the most probable capture-zone area range of 23 to 25 acres determined from the Monte-Carlo data. The area for NC-2 based on best-estimate values is 50 acres, whereas the most probable area based on the Monte-Carlo data is between 50 and 54 acres. The capture-zone area of NC-4 based on best-estimate values is 135 acres, whereas the Monte-Carlo data predicts two most-probable area ranges: 110 to 130 acres and 150 to 170 acres. The best-estimate capture-zone area of 135 acres falls in between these two most probable ranges.

Recommendations

Based on these findings I recommend that the City of North Canton locate paired monitoring wells in the Massillon Sandstone and glacial-drift around each well at appropriate positions to intercept possible contaminant flowpaths within the ground-water flow system. Figure 40 shows the 1-year capture zones of the three municipal bedrock wells computed

Table 5

Comparison of Capture-Zone Areas Based on the Best-Estimate Values with Areas Based on the Monte-Carlo Simulations

Well	Best-Estimate Area (acres)	Most Probable Area Range (acres)
NC-1	23	23 to 25
NC-2	51	50 to 54
NC-4	135	110 to 130

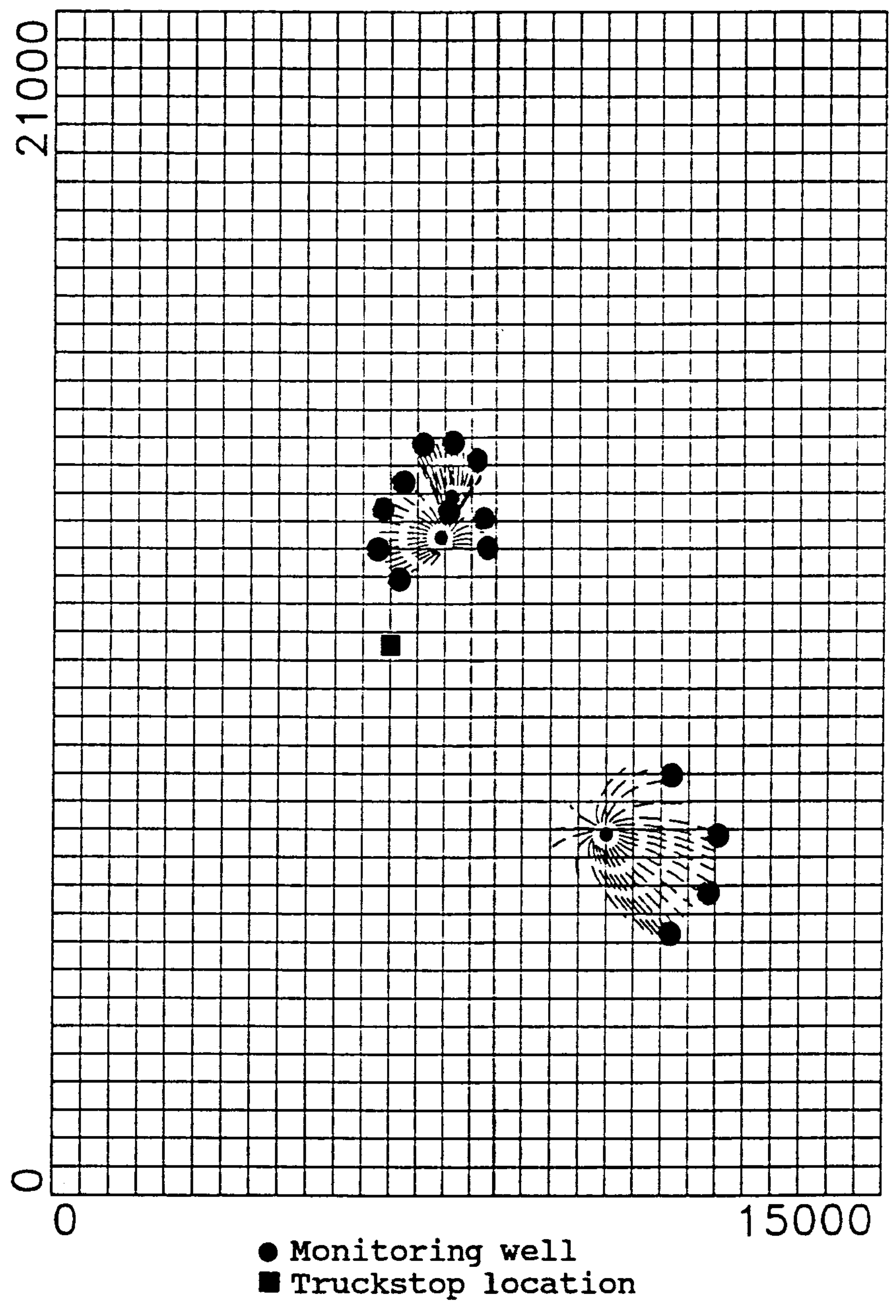


Figure 40. Recommended monitoring well locations.

using the best-estimate values of hydraulic parameters with suggested positions for the locations of these monitoring wells. The number of monitoring wells placed around the municipal wells may be dependent on economic factors and, therefore, the following suggestions are the minimal requirements.

Monitoring wells should be placed both in the Massillon Sandstone and in the glacial drift because the Massillon Sandstone aquifer is a leaky confined aquifer in which vertical leakage occurs from the overlying glacial-drift aquifer across the intervening shale unit. The best-estimate vertical hydraulic conductivity of the shale, 0.012 ft/d, is much lower than the best-estimate horizontal hydraulic conductivity of the Massillon Sandstone, 49 ft/d. Thus, it would take considerably longer for a contaminant to migrate downward across the shale layer than it would to migrate laterally within the Massillon Sandstone. Nonetheless, the importance of having monitoring wells within the glacial-drift aquifer also is justified because pumping in the Massillon Sandstone and concomitant vertical leakage from the glacial-drift aquifer causes a subdued cone of depression to form in it which is centered about the pumping well. As a result a contamination plume moving within the glacial-drift aquifer can be induced into the lower Massillon Sandstone aquifer.

Figure 40 indicates that paired monitoring wells peripheral to NC-4 completed in the Massillon Sandstone and in the glacial drift are located on the perimeter of the 1-year capture zone on the upgradient eastern side of the municipal well in a position to intercept contaminants traveling in the predominant direction of ground-water flow. At NC-2 paired monitoring wells should be constructed along the perimeter of the 1-year capture zone on the western and eastern sides of the capture zone. A pair of monitoring wells also is located between NC-2 and NC-1 to intercept any migration of contaminants downgradient from NC-1 which presently is contaminated. Paired monitoring wells around NC-1 are located upgradient based on the large concentration of flowpaths in that direction.

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APPENDIX A

Table 1. - GENERALIZED COLUMN OF PENNSYLVANIAN BEDROCK IN STARK COUNTY

Member	General description	Thickness Ft.	In.
	CONEMAUGH GROUP		
Lower Mahoning	Shale, thin-bedded, and channel-fill sandstone, conglomeratic.	20 to 130 ft.	
	ALLEGHENY GROUP		
Upper Freeport (No. 7)	Coal, variable	2	0
	Clay	4	0
Upper Freeport	Limestone, discontinuous	3	0
Bolivar	Coal and clay, thin, discontinuous	0	3
Shawnee	Limestone, thin, discontinuous	0	4
Upper Freeport	Shale and sandstone	60	0
Dorr Run	Shale, marine, local	0	6
Lower Freeport (No. 6a)	Coal, generally thin but persistent	0	10
	Clay	3	6
Lower Freeport	Limestone, nodular to bedded, discontinuous	1	7
Lower Freeport	Shale below, sandstone above	50	0
Upper Kittanning	Coal and clay, very local	0	2
	Shale	23	0
Washingtonville	Shale, marine; limestone nodules, discontinuous	0	10
Middle Kittanning (No. 6)	Coal, good	2	4
	Clay, plastic	6	0
Leetonia	Nodular siderite	0	6
	Coal, thin, local	0	1
Middle Kittanning	Shale	17	0
Strasburg (No. 5a)	Coal, generally thin, local	0	9
Oak Hill	Clay, siliceous	0	6
Strasburg	Shale, dark; concretions	11	0
Columbiana	Shale, marine; limestone nodules	1	2
Lower Kittanning (No. 5)	Coal, good	2	0
	Clay, plastic	6	0
Lawrence	Coal and clay, very local	0	2
	Shale	16	0
Vanport	Limestone, marine, discontinous	8	0
Clarion	Shale	50	0
Putnam Hill	Limestone and marine shale	10	0
Brookville (No. 4)	Coal, good	2	0

Table 1. - GENERALIZED COLUMN OF PENNSYLVANIAN BEDROCK IN STARK COUNTY (con.)

Member	General description	Thickness Ft.	In.
	POTTSVILLE GROUP		
Brookville	Clay	4	0
Homewood	Shale and channel-fill sandstone	15 to 35 ft.	
Tionesta (No. 3b)	Coal, discontinuous	0	6
	Clay, local, plastic to siliceous	8	0
	Shale and sandy shale	10	0
Upper Mercer	Limestone, marine, dark, dense; locally contains flint	2	0
Bedford	Coal, persistent, irregular	1	6
	Clay, plastic	1	6
	Shale, soft	23	0
Lower Mercer	Limestone, marine, dark, dense	2	6
Middle Mercer	Coal, irregular	1	6
	Clay, plastic	2	0
	Shale and fine-grained sandstone	15	0
Flint Ridge	Coal	1	0
	Clay	2	5
	Shale	15	0
Boggs	Limestone, marine, irregular	2	0
Lower Mercer (No. 3)	Coal	0	6
	Clay	3	0
	Shale, silty	18	0
Vandusen	Coal	0	6
	Clay, siliceous	0	7
	Shale, silty; and siltstone	14	0
Bear Run	Coal, thin	0	3
Massillon	Sandstone, massive; or shale	30 to 100 ft.	
Quakertown (No. 2)	Coal, persistent, generally thin	1	0
	Clay, (no data available)	-	-
	Shale, siliceous	34	0
Anthony	Coal, smut	0	2
Sciotoville	Clay, plastic, siliceous	5	0
	Shale	30	0
Sharon (No. 1)	Coal, lenticular	0 to 5 ft.	
	Clay (no data available)	-	-
Sharon	Conglomerate and sandstone; largely below drainage	? to 200 ft.	

APPENDIX B

Measured Water-Level Data

OWNER	ADDRESS	WELL NO.	WELL TYPE	COLLAR ELEV	DEPTH TO WATER 5/89	WATER-LEVEL ELE 5/89	DEPTH TO WATER 10/89	WATER-LEVEL ELEV 10/89
N. Canton	Freedom Ave	NC-1	B	1072	32.65	1039	34.26	1038
N. Canton	Freedom Ave	NC-2	B	1070	45.7	1024	48.28	1022
N. Canton	Dressler	NC-3	G	1061	18.7	1042	23.45	1038
N. Canton	Glenwood	NC-4	B	1060	9.45	1051	63.66	996
N. Canton	Dressler	NC-5	G	1065	45.6	1019		1065
J. Miller	6993 Frank	CMS-1	G	1120	10.28	1110	10.18	1110
Wyles	5114 Bob White	CMS-2	G	1122	7.4	1115	7.02	1115
McDonald	7066 Wren Dr	CMS-3	B	1121	8	1113		1121
Kaiser	5170 Bob O Link	CMS-4	G	1122	8.38	1114	8.95	1113
Kelby	7841 Frank	CMS-5	B	1100	8.6	1091	9.8	1090
Cioca	5110 Echo Valle	CMS-6	B	1133	43.15	1090		1133
Talavasky	4745 Echo Valle	CMS-7	B	1115	65.7	1049		1115
Deiringer	5626 Frank	CMS-8	B	1127	41.85	1085		1127
Wiseman	6093 Frank	CMS-9	B	1120	37	1083	36.62	1083
	4945 Sharonwood	CMS-10	B	1122	81.65	1040	81.82	1040
Callas	3024 Bambi	CMS-11	B	1052	40	1012		1052
Evans	1265 Lorrell	CMS-12	B	1140	35.6	1104	38.36	1102
Evergreen	1245 Main St	CMS-13	B	1149	25.1	1124	19.68	1129
Foltz	1005 Pittsburg	CMS-14	B	1098	32.9	1065		1098
M. Kepler	7439 Pittsburg	CMS-15	B	1105	51.7	1053	53.92	1051
Moon	3687 Orion	CMS-16	B	1162	73.15	1089	75.28	1087
Heid	3472 Orion	CMS-17	B	1166	20.2	1146	20	1146
Oakcrest	3559 Mt Pleasan	CMS-18	B	1186	88.42	1098	90.95	1095
Wines	3950 Mt Pleasan	CMS-19	B	1125	35	1090	43.08	1082
A.J. Herm	4032 Mt Pleasan	CMS-20	G	1115	28.85	1086	29.82	1085
VSF Const.	4665 Shuffel	CMS-21	B	1099	17.7	1081		1099
Liq Control	7576 Freedom	CMS-22	B	1082	17.9	1064		1082
C.M. McBride	4071 Strasser	CMS-23	B	1090	38	1052		1090
Accu Tool Co	7295 Sunset	CMS-24	B	1085	20.5	1065		1085
Serbian Hall	Wayview	CMS-25	B	1102	35.4	1067		1102
U Store It	5820 Dressler	CMS-26	B	1070	20	1050		1070
J. Bauder	3095 Bernwood	CMS-27	B	1069	27	1042		1069

CARBON PAPER NECESSARY— SELF-TRANSCRIBING

DEPARTMENT OF NATURAL RESOURCES
Division of Water
65 S. Front St., Rm. 815 Phone (614) 469-2646
Columbus, Ohio 43215

No. 401661

NC-3

County Stark Township Jackson Section of Township

Owner City of North Canton Address North Canton, O.

Location of property Dressler Road + Rte 77

CONSTRUCTION DETAILS

Casing diameter 36"x26" Length of casing 55'

Type of screen St Stl. Length of screen 25'

Type of pump Turbine

Capacity of pump 1500 GPM

Depth of pump setting 55'

Date of completion Aug. 18, 1970

BAILING OR PUMPING TEST
(Specify one by circling)

Test Rate 1000 G.P.M. Duration of test 72 hrs

Drawdown 21' 5 3/4" ft. Date Aug 14, 1970

Static level-depth to water ft.

Quality (clear, cloudy, taste, odor) Clear

elevation - 1061

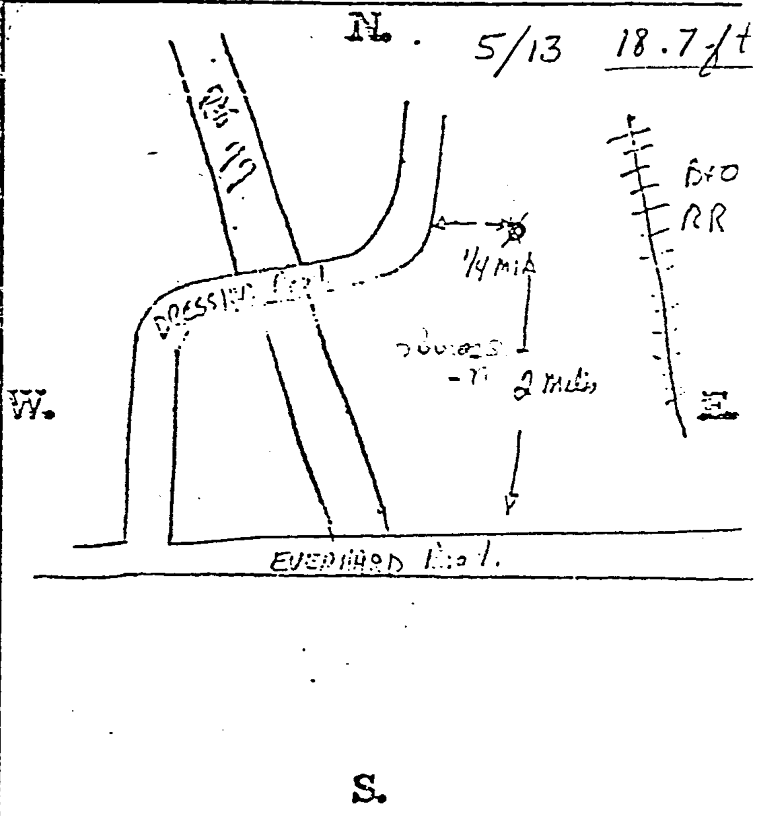
Pump installed by

WELL LOG*

Formations Sandstone, shale, limestone, gravel and clay	From	To
Manure fill	0 Feet	5 Ft.
Sand Gravel + Clay	5	30'
Sand Gravel + little Clay	30	45'
Sand + Gravel	45	80'
Sand, Gravel + large Stones	80	85'
Clay, Sandrock + Shale	85	90'

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



Drilling Firm

Address Massillon, O

Date August 31, 1970

Signed

If additional space is needed to complete well log, use next consecutive numbered form.

LOCATED

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Columbus, Ohio

No. 133859

69

County Stark Township Plain Section of Township or Lot Number B NC-4

Owner Village of North Canton Address North Canton Ohio

Location of property 1800 Ft East of Wise Road + 250 Ft North of Dressler Ro

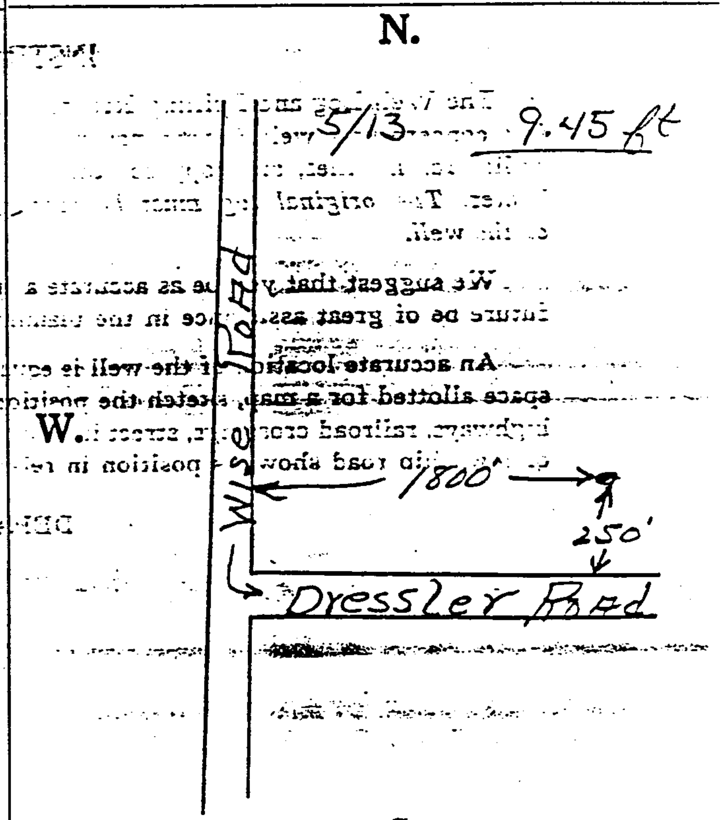
CONSTRUCTION DETAILS		PUMPING TEST	
Casing diameter 20"	Length of casing 41' 7"	Pumping rate 600 G.P.M.	Duration of test 48
Type of screen ✓	Length of screen ✓	Drawdown 32 ft.	Date Feb 2-195
Type of pump Deep Well Turbine		Developed capacity 600 GPM.	
Capacity of pump 600 GPM.		Static level—depth to water 4	
Depth of pump setting 90'		Pump installed by Dyer	
		elevation = 1060 ft	

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Loam + Clay	0 Feet	14 Ft.
Clay + Gravel	14	28
Soft Sand Rock	28	41
Sand Rock	41	97
Shale	97	116
Sand Rock	116	207
Shale	207	224
Sand Rock	224	329
Shale + Lime	329	344
Gray Shale	344	397

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



See reverse side for instructions

Drilling Firm Ohio Drilling Co. Date Feb. 7-1955

Address Massillon Ohio Signed John H. Musgarber

69

County Permit No

WELL LOG AND DRILLING REPORT

ORIGINAL

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

NO CARBON PAPER NECESSARY—SELF-TRANSCRIBING

529045
G NC-5

4/24 43.9 ft pumping
5/13 45.6 ft pumping

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP

OWNER City of North Canton, Ohio ADDRESS

LOCATION OF PROPERTY Dressler Rd. Well Field.

CONSTRUCTION DETAILS

Casing diameter 36" 16" Length of casing 61 ft.

Type of screen S.S. Length of screen 20 ft.

Type of pump Not yet Installed

Capacity of pump —

Depth of pump setting —

Date of completion 9/21/78

BAILING OR PUMPING TEST

(specify one by circling)

Test rate 1000 gpm Duration of test 8 hrs

Drawdown 18 ft Date 9/20/78

Static level (depth to water) 17'3" ft

Quality (clear, cloudy, taste, odor) —

elevation, — 1065

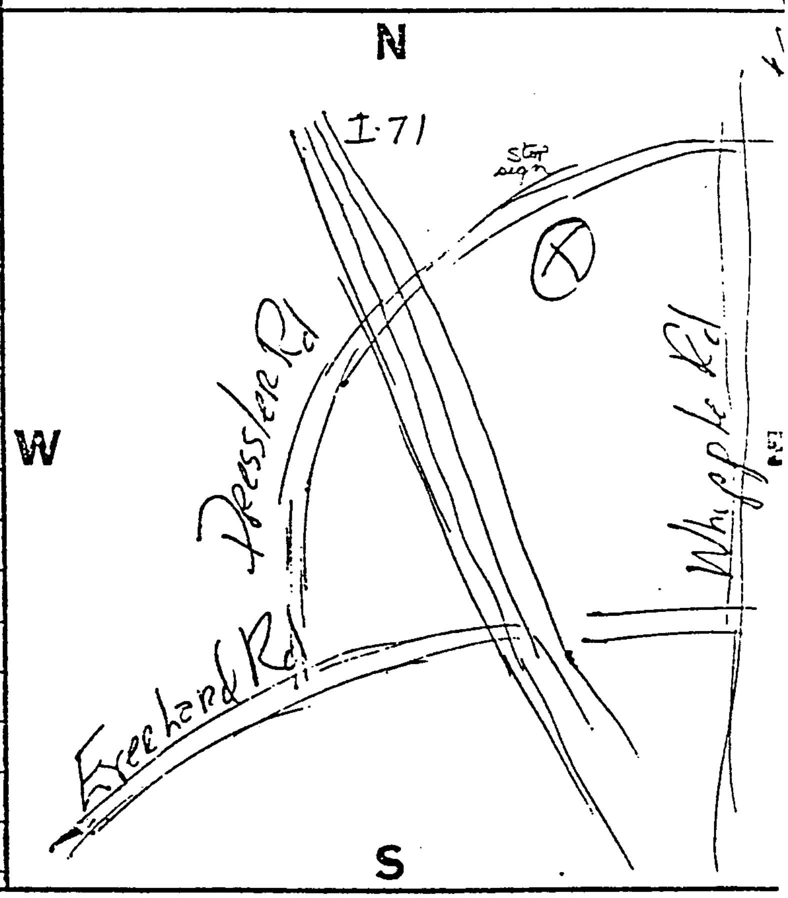
Pump installed by —

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
Fill Clay Sand + Gravel	0 ft	34 ft
Sd. Gravel + Little Clay	34	48
Sand & Gravel	48	65
Sand + Gravel w/Clay Layer	65	69
Sand & Gravel + Some Clay	69	76
Soft Sandrock	76	86

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.



DRILLING FIRM The Ohio Drilling Co. DATE 9/27/79

ADDRESS Massillon, Ohio SIGNED R. Smith

△ sand + gravel

WELL LOG AND DRILLING REPORT

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus, Ohio

PLEASE USE PENCIL OR TYPEWRITER. DO NOT USE INK.

G CMS-1

No. 227121

County Stark Township Jackson Section of Township 11

Owner Joe Miller Address 5514 ~~Frank-R~~ Island Dr. Canton

Location of property 6993 Frank Rd. North Canton, Ohio

CONSTRUCTION DETAILS

Casing diameter 4 in. Length of casing 30

Type of screen Length of screen

Type of pump

Capacity of pump

Depth of pump setting

Date of completion

BAILING OR PUMPING TEST

Pumping rate G.P.M. Duration of test hr

Drawdown none ft. Date

Developed capacity 12 gal per min

Static level—depth to water 10

Pump installed by

elevation - 1120 ft

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
sand	0 Feet	30 Ft.
gravel	30	33

SKETCH SHOWING LOCATION

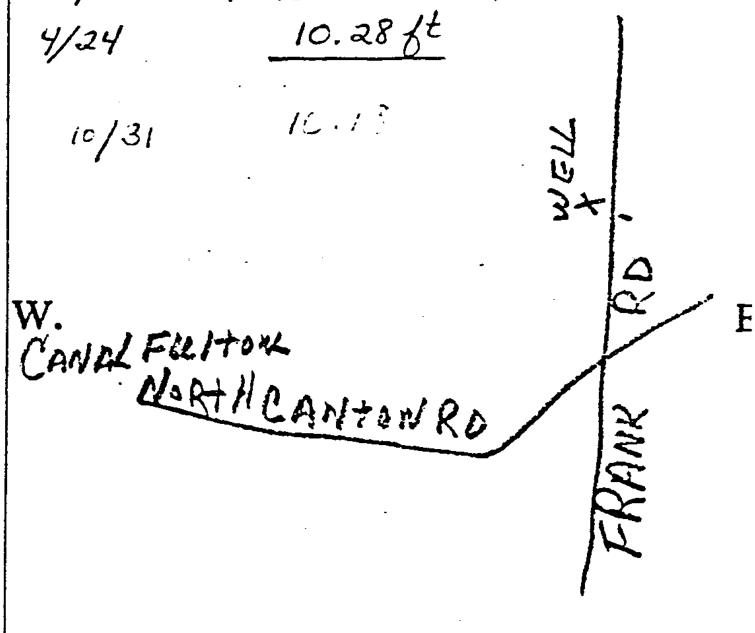
Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

N.

Measurement Water depth:

4/24 10.28 ft

10/31 10.13



S.

See reverse side for instructions

Drilling Firm Paul Rhoades Date Jan. 5, 1959

Address Canal Fulton, Ohio Signed

△ Sand & gravel

WELL LOG AND DRILLING REPORT

680207

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

DA

G CMS-2

Permit Number 4909

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP 11

OWNER Wyles Heating ADDRESS 6895 Frank Rd. NW

LOCATION OF PROPERTY 5114 Bob White N. Canton

CONSTRUCTION DETAILS

Casing diameter 5" Length of casing 46'

Type of screen Length of screen

Type of pump

Capacity of pump

Depth of pump setting

Date of completion
Rotary ☐ or Cable ☐

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 18 gpm Duration of test 1 h

Drawdown 8 ft Date 4/21/88

Static level (depth to water) 6'

Quality (clear, cloudy, taste, odor) clear

elevation - 1122 ft.

Pump installed by

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
sand & gravel	0 ft	45 ft
perforated point		

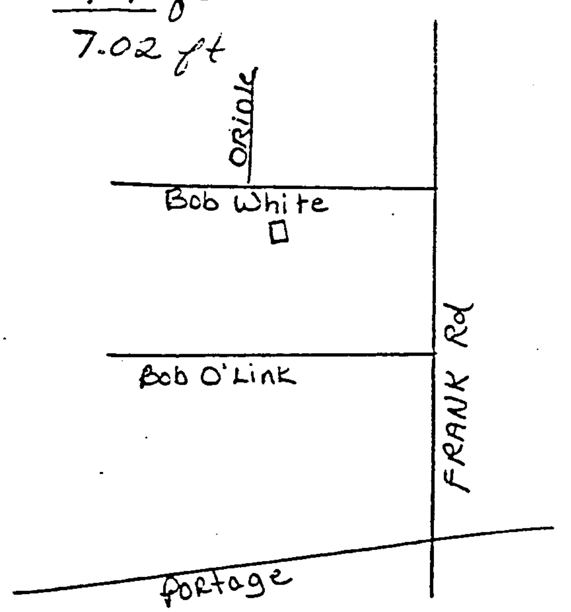
SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.

N

Measurement
4/24 7.4 ft.
10/31 7.02 ft

W



S

* If additional space is needed to complete well log, use next consecutively numbered form.

DNR 780:

DRILLING FIRM Adams & Sons REGISTRATION NUMBER 395 DATE 4/27/88

ADDRESS 1174 Mt. Pleasant NW N.Canton, OH SIGNED Deborah Adams

Completion of this form is required by 1521.05, Ohio Revised Code - file within 30 days after completion.

WHITE ORIGINAL COPY - ODNR, DIVISION OF WATER, FOUNTAIN SQ., COLS., OHIO 43224 / Blue - Customer's Copy / Pink - Driller's Copy / Green - Local Health Dept. Copy

?? bedrock

WELL LOG AND DRILLING REPORT

Water levels

CMS - 3

ORIGIN

PLEASE USE PENCIL
OR TYPEWRITER
DO NOT USE INK.

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus 12, Ohio

B

No 290256

4/24 8.0 ft depth to water

County Stark Township Jackson Section of Township 11

Owner McDonald & Mattei Address Canton

Location of property 7066 Wren Dr off Frank Rd

CONSTRUCTION DETAILS

Casing diameter 4" Length of casing 71'

Type of screen .... Length of screen ....

Type of pump ....

Capacity of pump ....

Depth of pump setting ....

Date of completion ....

BAILING OR PUMPING TEST

Pumping Rate 15 G.P.M. Duration of test 1 hrs.

Drawdown 4 ft. Date 2-20-63

Static level-depth to water 35 ft.

Quality (clear, cloudy, taste, odor) ....

elevation - 1121 ft

Pump installed by ....

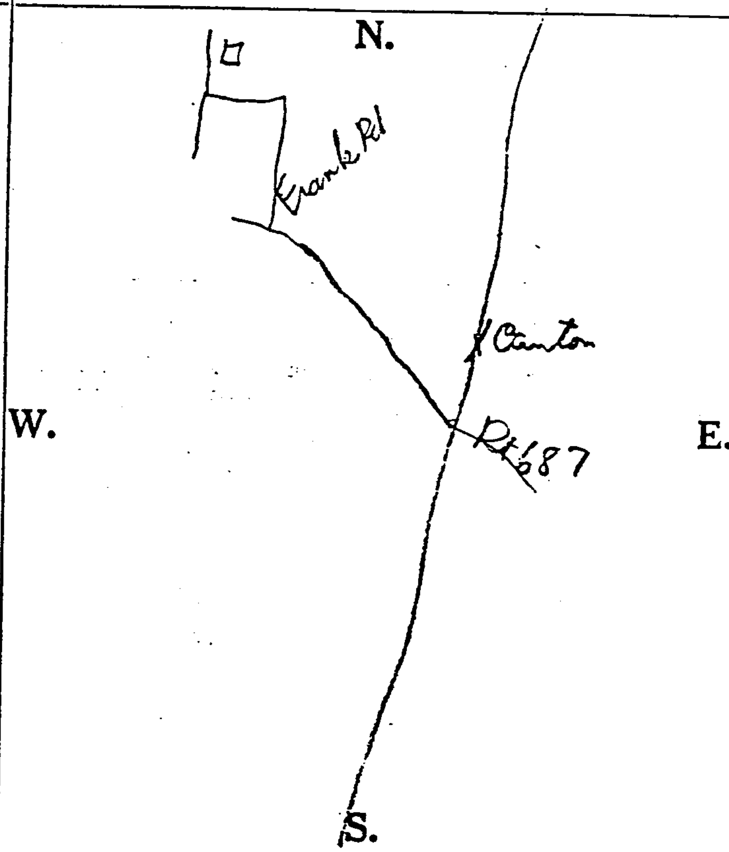
WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Brown Sand	0 Feet	31 Ft.
Grey Sand	31	60
Gravel	60	67
Shale grey	67	77

water @ 75'

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



See reverse side for instructions

Drilling Firm J J Skolnik

Address 7971 Cleveland SE
Magnolia O

Date 4-1-63

Signed J J Skolnik

LOCATED

sand + gravel

WELL LOG AND DRILLING REPORT

G CMS-4

№ 286495

yes

PLEASE USE PENCIL
OR TYPEWRITER
DO NOT USE INK.

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus 12, Ohio

County Stark Township Jackson Section of Township 11

Owner Kaiser Homes Address 5170 Bob O'Link N. Canton, O.

Location of property Going north on Frank Rd. turn left onto Bob O Link. House on north side

CONSTRUCTION DETAILS

Casing diameter 4 inch Length of casing 54 ft.

Type of screen Length of screen

Type of pump

Capacity of pump

Depth of pump setting

Date of completion

BAILING OR PUMPING TEST

Pumping Rate 16 G.P.M. Duration of test hrs.

Drawdown 3 ft. Date

Static level-depth to water 8 ft.

Quality (clear, cloudy, taste, odor)

elevation - 1122 ft

Pump installed by

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
muck	0 Feet	25 Ft.
yellow clay sand	25	45
yellow gravel & Sand	45	54
total depth	54 feet	

SKETCH SHOWING LOCATION

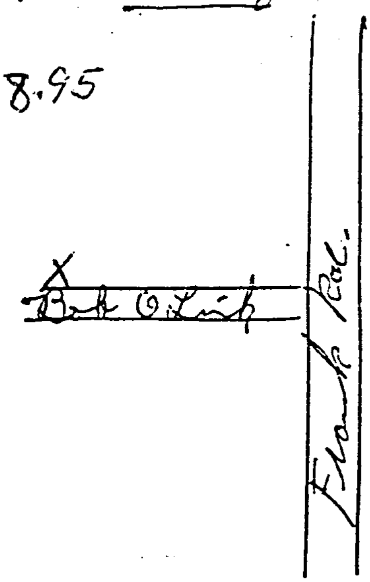
Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

N.

Measurement
4/24 8.38 ft.

10/31 8.95

W. E.



S.

See reverse side for instructions

Drilling Firm Parker Graham Date 12/13/62

Address 1174 Mt. Pleasant NW, N. Canton 20, Ohio Signed Parker Graham

County Permit No. ____

WELL LOG AND DRILLING REPORT

B

ORIGINAL

CMS-5

563065

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP ____

OWNER Ron Kelby ADDRESS 7841 Frank Road, N. Canton, O. 44720

LOCATION OF PROPERTY Same

CONSTRUCTION DETAILS

Casing diameter 5" Length of casing 32' 1"

Type of screen ____ Length of screen ____

Type of pump ____

Capacity of pump ____

Depth of pump setting ____

Date of completion ____

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 30 gpm Duration of test 2 h

Drawdown 13 ft Date ____

Static level (depth to water) 12

Quality (clear, cloudy, taste, odor) some odor

elevation - 1100 ft.

Pump installed by ____

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
Wash	0 ft	10 ft
Coal & Clay 1896	10	25
Coal	25	32
Plastic shale (gray)	32	35
Gray Shale	35	40
Gray Sandy Shale	40	50
Gray	50	61

SKETCH SHOWING LOCATION

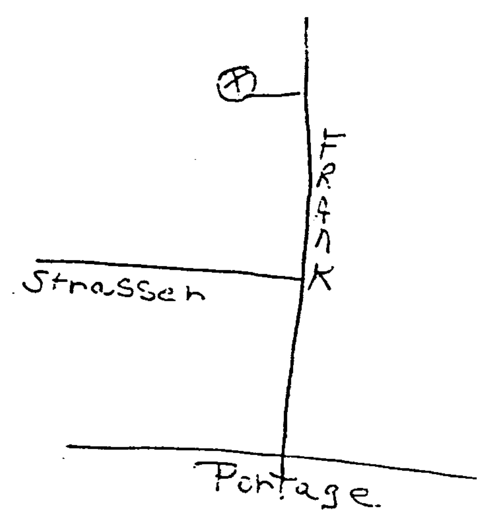
Locate in reference to numbered state highways, street intersections, county roads, etc.

N

5/13 8.6 ft

10/31 9.8

W



S

DRILLING FIRM Stockert Drilling Company DATE March 18, 1980

ADDRESS Strasburg, Ohio 44680 SIGNED Barbara M. Stockert

*If additional space is needed to complete well log, use next consecutive numbered form.

B CMS-6 ORIGIN

WELL LOG AND DRILLING REPORT

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus, Ohio 43212

come back

Nº 332004

PLEASE USE PENCIL OR TYPEWRITER
DO NOT USE INK.

County: Stark   Township: Jackson   Section of Township: 24

Owner: Dennis Cisca   Address: 1103 Dartmouth S.W. Canton

Location of property: 5110 Echo Valley Dr. N.W.

CONSTRUCTION DETAILS

Casing diameter: 5"   Length of casing: 94'

Type of screen: Length of screen:

Type of pump: Jet

Capacity of pump: 7 gpm

Depth of pump setting: 70 ft.

Date of completion: 6-16-65

BAILING OR PUMPING TEST

Pumping Rate: 20 G.P.M. Duration of test: hrs

Drawdown: 15 ft. Date: June 15th

Static level-depth to water: 40 ft

Quality (clear, cloudy, taste, odor): [illegible]
[illegible] hard

Pump installed by: Everett Waltz & Co. Inc.

WELL LOG*

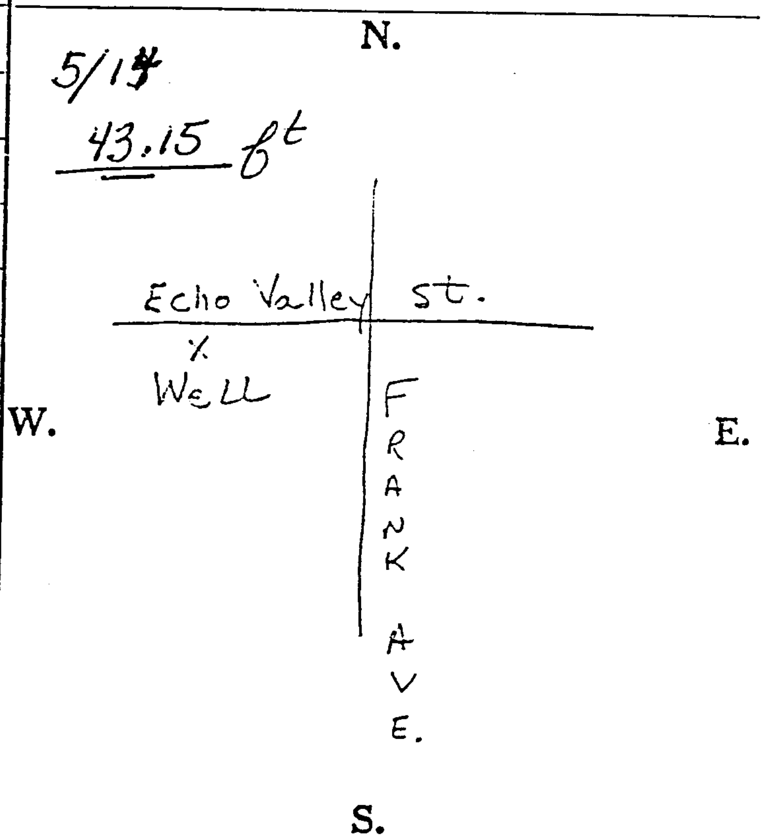
Formations Sandstone, shale, limestone, gravel and clay	From	To
Pit	0 Feet	7 Ft.
Brown Gravel	7	61
Gray Sandstone	61	70
Gray Sand Gravel	70	88
coal	88	89
Soft Clay	89	96
Sandrock	96	105
Gray Plastic	105	108
Gray Sand Shale	108	115
Dark Plastic Shale	115	120
water at	100-	105

SKETCH SHOWING LOCATION

elevation - 1133 ft

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

5/14
43.15 ft



See reverse side for instructions

Drilling Firm: EVERETT WALTZ & CO. Inc. DRILLING CONTRACTORS
Address: STRASBURG, OHIO

Date: Aug. 30, 1965
Signed: Nick Howell

*If additional space is needed to complete well log, use next consecutive numbered form.

bedrock

WELL LOG AND DRILLING REPORT

B- CMS-7
692112

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1939 Fountain Square Drive
Columbus, Ohio 43224

TYPE OR USE PEN
SELF-TRANSCRIBING
PRESS HARD!

Permit Number 55218

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP

OWNER Miles Talavasky PROPERTY ADDRESS 4745 Echovalley Rd. N.W.

LOCATION OF PROPERTY South of Portage Rd., off of Frank Rd. East.

CONSTRUCTION DETAILS

CASING

Casing Diameter 5 in. Length of Casing 123 ft

Type: ☐ Steel ☐ Galv. ☒ PVC ☐ Other

Joints: ☐ Threaded ☐ Welded ☒ Solvent ☐ Other

SCREEN

Type (wire wrapped, louvered, etc.) Material

Length ft Diameter in.

Set between ft. and ft. Slot

GROUT

Material Fire Clay Volume used 700#

Method of installation cable tool method

Depth: placed from top ft. to 95 ft.

☐ Rotary ☒ Cable ☐ Augered ☐ Driven ☐ Dug ☐ Other

BAILING OR PUMPING TEST
(specify one by circling)

WELL TEST

Test rate 15 gpm Duration of test 1 hrs

Drawdown (water level during pumping) 10 ft

Measured from: ☐ top of casing ☒ ground level ☐ Other

Static Level (depth to water) 75 ft Date: 12-10-88

Quality (clear, cloudy, taste, odor) Clear 6GH 7.2PH 1 Iron

PUMP

Type of pump Sub. Capacity 7 gpm

Pump set at 120 ft

Pump installed by Jenei Drilling Co., Inc.

Pitless Device ☒ Adapter ☐ Preassembled unit

Use of Well Domestic

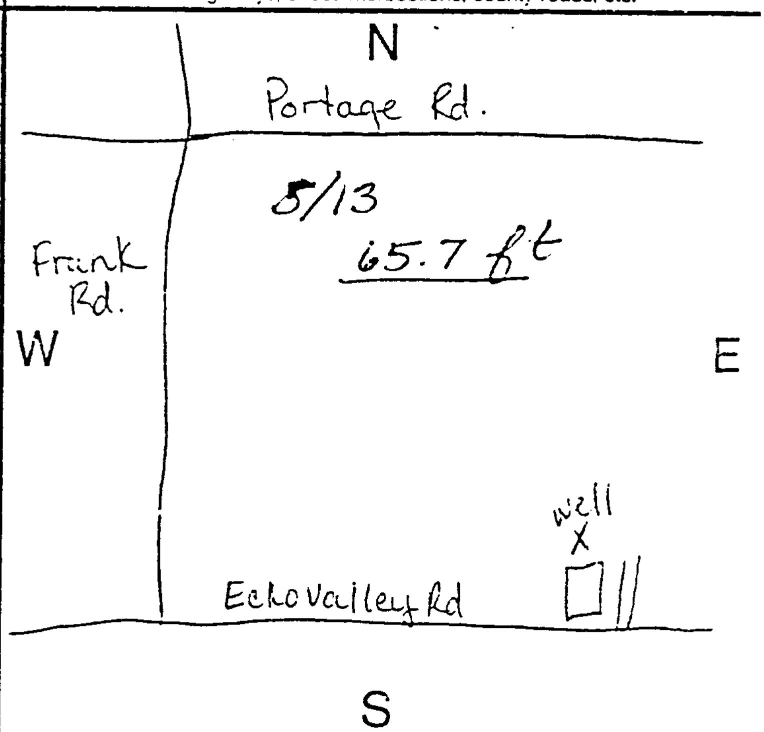
elevation - 1115 ft

WELL LOG*

Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand	From	To
ddy sand gravel	0 ft	60 ft
Gray mud	60'	70'
Gray shale	70'	125'
Light Sandy shale	126'	143'
Gray shale	143'	159'
Gray sandy shale	159'	187'
Light Sandrock	187'	205'

SKETCH SHOWING LOCATION

Show distances well lies from numbered state highways, street intersections, county roads, etc.



* If additional space is needed to complete well log, use next consecutively numbered form.

DNR 7802.8

DRILLING FIRM Jenei Drilling Co. SIGNED Robert L Jenei

ADDRESS P.O. Box 67 DATE January 5, 1988

CITY, STATE, ZIP Strasburg, OH 44680 ODH REGISTRATION NUMBER 31

Completion of this form is required by 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.

ORIGINAL COPY - ODNR DIVISION OF WATER

bedrock

WELL LOG AND DRILLING REPORT

CMS#8

ORIGINAL

B

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
65 S. Front St., Rm. 815 Phone (614) 469-2646
Columbus, Ohio 43215

450701

County Stark Township Jackson Section of Township

Owner Leroy Deiringer Address 5541 Sandalwood N. E. North Canton

Location of property 5626 Frank Rd

CONSTRUCTION DETAILS	
Casing diameter	5"
Length of casing	100'4"
Type of screen	
Length of screen	
Type of pump	
Capacity of pump	
Depth of pump setting	
Date of completion	

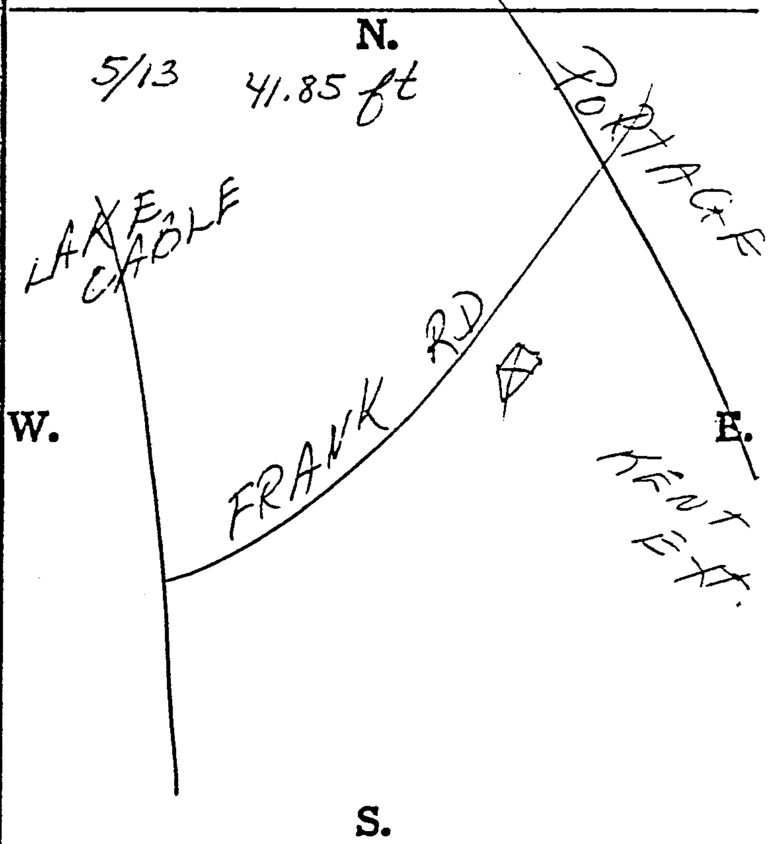
BAILING OR PUMPING TEST (Specify one by circling)	
Test Rate	14 G.P.M.
Duration of test	1 hrs.
Drawdown	20' ft.
Date	11/10/72-11/13/72
Static level-depth to water	40' ft.
Quality (clear, cloudy, taste, odor)	
	elevation - 1127 ft
Pump installed by	

WELL LOG*

Formations Sandstone, shale, limestone, gravel and clay	From	To
Wash formation	0 Feet	79' Ft.
Gray plastic shale	79'	83'
Coal	83'	84'
Clay	84'	86'
Gray sandy shale	86'	97'
Sandrock	97'	120'

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



Drilling Firm Stockert Drilling Co. Inc. Date December 6, 1972

Address Strasburg, Ohio Signed Walter A. Stockert

Bedrock

WELL LOG AND DRILLING REPORT

CMS-9 B

Water levels

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

620207

4/24 37.01 ft.

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP

OWNER Larry Wiseman ADDRESS 6093 ~~[illegible]~~ Frank N.W. N.Canton

LOCATION OF PROPERTY Same

CONSTRUCTION DETAILS

Casing diameter 5" Length of casing 77'

Type of screen Length of screen

Type of pump Submersible

Capacity of pump 10 GPM

Depth of pump setting 80'

Date of completion 4-3-77

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 20 gpm Duration of test 2 hr

Drawdown 25 ft Date 3-30-72

Static level (depth to water) 50'

Quality (clear, cloudy, taste, odor) Clear

elevation - 1120 ft.

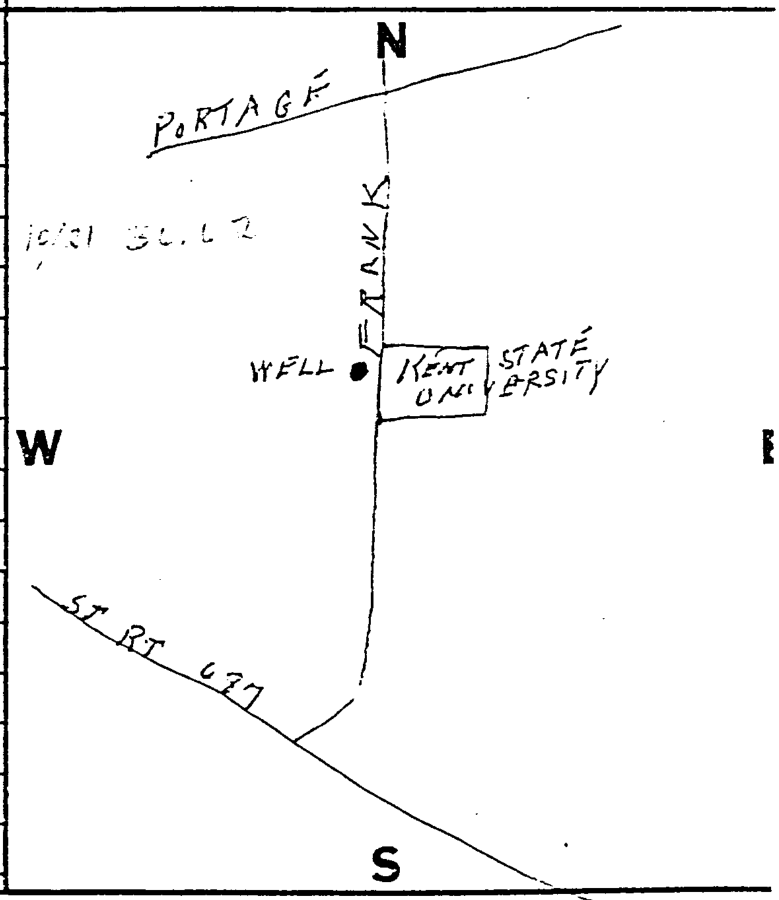
Pump installed by Spencer Drilling Inc

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
Clay & Gravel	0 ft	74 ft
Soft Shale	74	77
Shale	77	105

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.



DRILLING FIRM Spencer Drilling Inc DATE 4-7-82

ADDRESS 11490 Millersburg Rd Massillon SIGNED K Spencer

*If additional space is needed to complete well log, use next consecutive numbered form.

WELL LOG AND DRILLING REPORT

ORIGINAL

B CMS - 10

475742

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Geological Survey
Fountain Square
Columbus, Ohio 43224 Phone (614) 466-5344

H.B.

NO CARBON PAPER NECESSARY– SELF-TRANSCRIBING

permit #23636

COUNTY Stark TOWNSHIP Plain SECTION OF TOWNSHIP OR LOT NUMBER 19

OWNER Look Homes Inc. ADDRESS 2835 S. Nickel Plate, Louisvill Ohio

LOCATION OF PROPERTY 4945 Sharonwood, Canton,O

CONSTRUCTION DETAILS

asing diameter 4" Length of casing 60'

ype of screen ______ Length of screen ______

ype of pump ______

apacity of pump ______

epth of pump setting ______

ate of completion ______

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 10 gpm Duration of test 1 hrs

Drawdown 15 ft Date 8/14/75

Static level (depth to water) 80 ft

Quality (clear, cloudy, taste, odor) clear

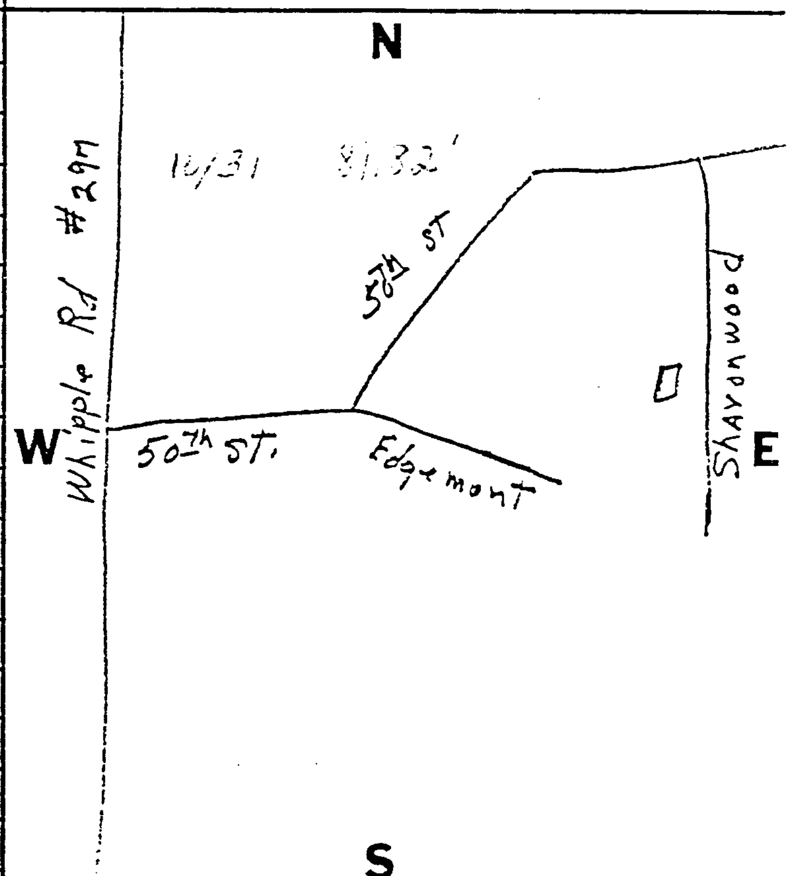
Pump installed by ______

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
drift	0 ft	36 ft
shale	36	42
limestone	42	45
shale	45	103
sandstone	103	148
shale	148	170

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.



DRILLING FIRM ADAMS & SONS Well Drilling, Inc. DATE 8/23/74

ADDRESS 4310 - 38th St., N.W. 492-0150 Canton, Ohio 44718 SIGNED [signature]

*If additional space is needed to complete

WELL LOG AND DRILLING REPORT

695576
B CMS-11

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1939 Fountain Square Drive JB
Columbus, Ohio 43224
(614) 265-6739

TYPE OR USE PEN
SELF-TRANSCRIBING
PRESS HARD!

Permit Number 101657

OUNTY Stark TOWNSHIP Plain SECTION/LOT NO. 19 (CIRCLE ONE)

WNER/BUILDER Mike Callas (IRCLE ONE OR BOTH) PROPERTY ADDRESS 3024 Bambi NW Canton (ADDRESS OF WELL LOCATION)

OCATION OF PROPERTY 38th St (#213) at 77 overpass N. on Orchardale to Bambi

CONSTRUCTION DETAILS land surf. elev.

ASING

iameter 5 in. Length 148 ft. Wall Thickness 0.244 in.

ype: ☒ Steel ☐ Galv. ☐ PVC ☐ Other

oints: ☒ Threaded ☐ Welded ☐ Solvent ☐ Other

CREEN

ype (wire wrapped, louvered, etc.) none Material

ength ft. Diameter in.

et between ft. and ft. Slot

Rotary ☒ Cable ☐ Augered ☐ Driven ☐ Dug ☐ Other

ate of completion 4/7/89

GROUT

Material Volume used

Method of installation

Depth: placed from ft. to ft.

GRAVEL PACK

Material Volume used

Method of installation

Depth: placed from ft. to ft.

Pitless Device ☐ Adapter ☐ Preassembled unit

Use of Well single family dwelling

PUMP

ype of pump Capacity gpm

ump set at ft.

ump installed by

WELL LOG*

ICATE DEPTH(S) AT WHICH WATER IS ENCOUNTERED.
v color, texture, hardness, and formation: tone, shale, limestone, gravel, clay, sand, etc.

	From	To
Drift	0 ft.	6 ft.
sand & gravel	6	136
shale	136	161
sandstone	161	180
H_2O at 180'		

WELL TEST

Bailing ☒ or Pumping ☐

Test rate 20 gpm Duration of test 1 hrs.

Drawdown 30 ft.

Measured from: ☒ top of casing ☐ ground level ☐ Other

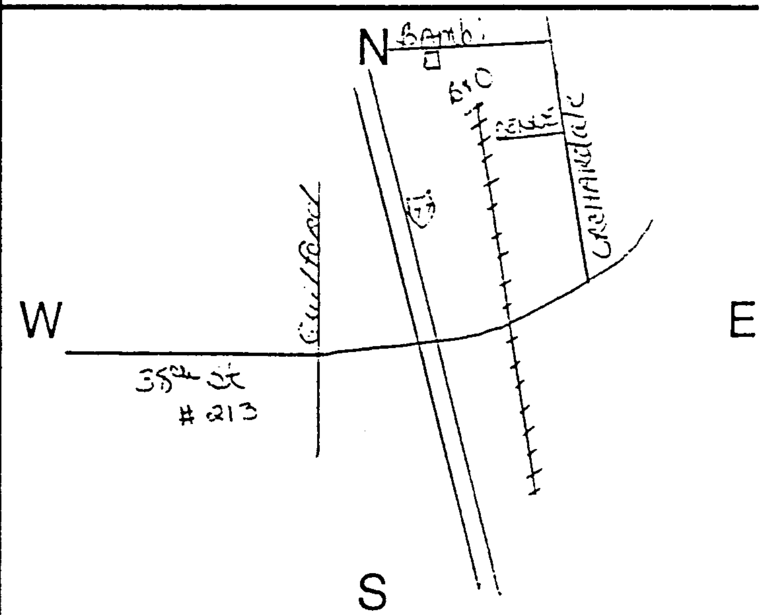
Static Level (depth to water) 40 ft. Date: 4/7/89

Quality (clear, cloudy, taste, odor) clear

(Attach a copy of the pumping test record, per 1521.05, ORC)

SKETCH SHOWING LOCATION

Show distances well lies from numbered state highways, street intersections, county roads, etc.



If additional space is needed to complete well log, use next consecutively numbered form

DNR 7802.88

LING FIRM Adams & Sons

IESS 1174 Mt. Pleasant NW

CITY, STATE, ZIP N.Canton, OH 44720

SIGNED Debbie Adams

DATE 4/10/89

ODH REGISTRATION NUMBER 395

Completion of this form is required by 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.

ORIGINAL COPY - ODNR, DIVISION OF WATER, 1939 FOUNTAIN SQ. DRIVE, COLS., OHIO 43224

ORIGINAL

WELL LOG AND DRILLING REPORT

B CMS-12

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus, Ohio 43212

No 351370

PLEASE USE PENCIL OR TYPEWRITER
DO NOT USE INK.

County Stark Township Plain Section of Township Hartville O

Owner Ellis Erb Address 13163 Market ave

Location of property 5723 [illegible] ave

CONSTRUCTION DETAILS

Casing diameter 5" Length of casing 30

Type of screen ______ Length of screen ______

Type of pump ______

Capacity of pump ______

Depth of pump setting ______

Date of completion ______

BAILING OR PUMPING TEST

Pumping Rate 7 G.P.M. Duration of test 1 hrs.

Drawdown 25 ft. Date 8-25-66

Static level-depth to water 99 ft.

Quality (clear, cloudy, taste, odor) ______

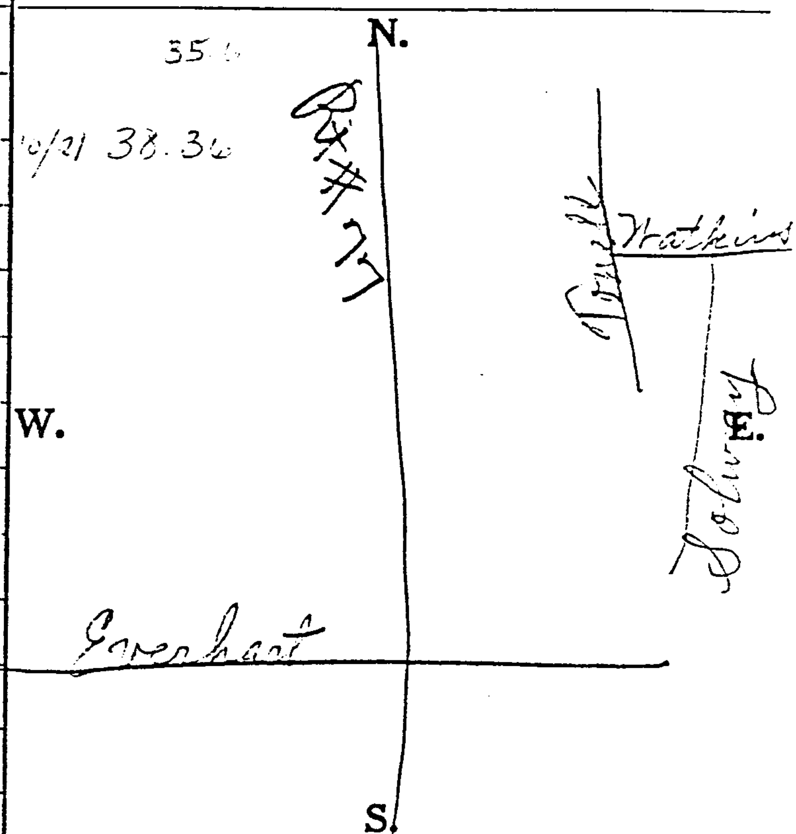
Pump installed by ______

WELL LOG*

Formations Sandstone, shale, limestone, gravel and clay	From	To
Clay	0 Feet	10 Ft.
Sand Stone	10'	35'
Shale	35'	115'
Sand Stone	115'	132

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



See reverse side for instructions

Drilling Firm L. E. Rusi Date 8-25-66

Address 310 Killian Rd Akron 19 O Signed L. Rosen

*If additional space is needed to complete well log, use next consecutive numbered form.

bedrock

WELL LOG AND DRILLING REPORT

ORIGIN

B CMS-13

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus 12, Ohio

PLEASE USE PENCIL OR TYPEWRITER DO NOT USE INK.

No. 283244

County Stark Township Plain Section of Township 7

Owner Evergreen Trailer Park Address 1245 Main St. North Canton

Location of property same

CONSTRUCTION DETAILS

Casing diameter 5" Length of casing 42' 6"

Type of screen .... Length of screen ....

Type of pump ....

Capacity of pump ....

Depth of pump setting ....

Date of completion ....

BAILING ~~OR PUMPING~~ TEST

Pumping Rate 20 G.P.M. Duration of test .... hrs.

Drawdown 5 ft. Date 12-20-65

Static level-depth to water 25 ft.

Quality (clear, cloudy, taste, odor) 1/2 ppm iron — 8 gr.

Pump installed by elevation - 1149 ft

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Pit	0 Feet	5 Ft.
Brown Wash	5	20'
Gravel + mud	20'	29'
Hard	29'	32'
Coal Was	32'	36'
Dark Shale Soft	36'	44'
Sandrock Hard	44'	48'
Gray Shale	48'	56'
Sandy Shale	56'	58'
Gray Plastic Shale	58'	62'

Water at 44'-62'

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

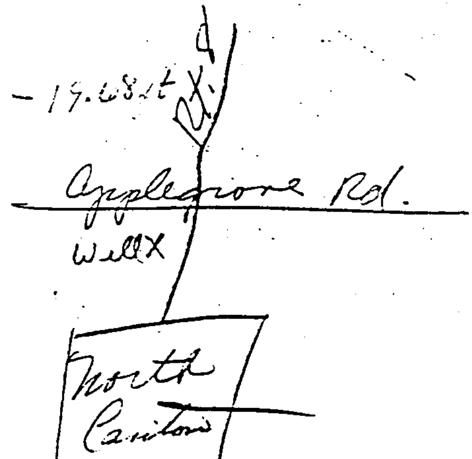
N.

5/13 25.1 ft older well near office

5/13

10 21 - 19.68 ft

W. E.



S.

See reverse side for instructions

Drilling Firm EVERETT WALTZ & CO. Inc. ~~DRILLING CONTRACTORS~~

Address STRASBURG, OHIO

Date 1-15-66

Signed A. D. Carr

24991 WELL LOG AND DRILLING REPORT

ORIGINAL

CMS-13 B

61

LOCATED

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Columbus, Ohio

№ 162307

County Stark Township Plain Section of Township or Lot Number 7

Owner Evergreen Trailer Court Address 1245 No Main St North Canton

Location of property Rte 8 edge N. Canton

CONSTRUCTION DETAILS	
Casing diameter 5"	Length of casing 44' 6" casing / 84' 5" "
Type of screen	Length of screen
Type of pump	
Capacity of pump	
Depth of pump setting	

Bailer ~~PUMPING~~ TEST	
Pumping rate G.P.M.	Duration of test h
Drawdown ft.	Date July 3 1955
Developed capacity 18 GPM	
Static level—depth to water 50	
Pump installed by	

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Gravel	0 Feet	20 Ft.
gray sandy mud	20	40
gray rock	40	50
gray plaster shale	50	55
Limestone	55	57
	58	58
Coal	58	60
Clay		
gray shale	60	70
gray plas shale	70	80
Limestone	80	81
Light plaster shale	81	83
Light sandy shale	83	88
gray plas shale	88	98
Coal	98	100
Light plas shale	100	107
gray sandy shale	107	155
gray sandrock	155	170

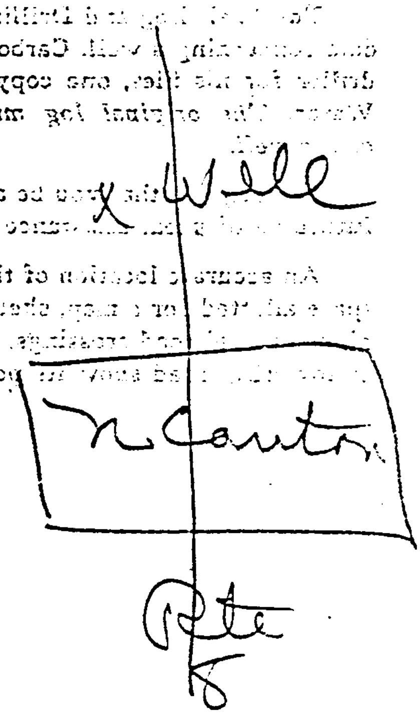
made water 10 gal per min at Rock 155 to 170

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

N.

W.



S.

See reverse side for instructions

Drilling Firm Everett Waltz & Co Inc Date Oct 18 1955

Address Strasburg Signed C. C. Steiner

61

2952

WELL LOG AND DRILLING REPORT

LOCATED

67

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Columbus, Ohio

No. 115813

Bedrock

B CMS-

County Stark Township Plain Section of Township or Lot Number 7 14

Owner Emerson Folts Address R.D. #9 North Canton O

Location of property 1005 Pittsburg

CONSTRUCTION DETAILS

Casing diameter 4 Length of casing 32'

Type of screen Length of screen

Type of pump

Capacity of pump

Depth of pump setting

PUMPING TEST

Pumping rate G.P.M. Duration of test hrs

Drawdown 40 ft. Date

Developed capacity 10 gpm

Static level—depth to water 19

Pump installed by

elevation - 1098 ft.

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Stoney Clay	0 Feet	16 Ft.
Shale	16	13
Coal	18	22
Fireclay	20	29
Gray shale	29	40
Gray sand Rock	40	92
	92	

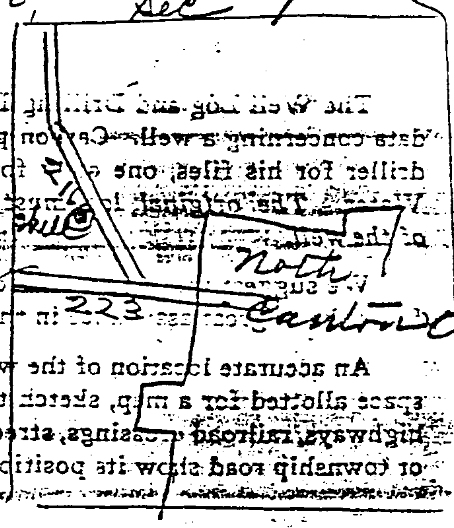
SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

N.

5/14

32.9 ft. Sec 7



W. E.

S.

See reverse side for instructions

Drilling Firm E. E. Wolf Date May 1 - 34 Fin June 7-

Address 2242 Lincoln Way W Signed E. E. Wolf

Massillon O

bedrock

WELL LOG AND DRILLING REPORT

CMS 15

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1939 Fountain Square Drive
Columbus, Ohio 43224

B 693691

TYPE OR USE PEN
SELF-TRANSCRIBING
PRESS HARD!

RB

Permit Number 100292

OUNTY Stark TOWNSHIP Plain SECTION OF TOWNSHIP 6

VNER Monte Kepler PROPERTY ADDRESS 7439 Pittsburg RD. NW N.Canton

OCATION OF PROPERTY couple houses North of Pittsburg #216 & Applegrove #190 intersection

CONSTRUCTION DETAILS

ASING

asing Diameter 5 in. Length of Casing 54 ft.

pe: ☒ Steel ☐ Galv. ☐ PVC ☐ Other

ints: ☒ Threaded ☐ Welded ☐ Solvent ☐ Other

CREEN

pe (wire wrapped, louvered, etc.) Material

ngth ft. Diameter in.

et between ft. and ft. Slot

ROUT

aterial Volume used

ethod of installation

epth: placed from ft. to ft.

Rotary ☒ Cable ☐ Augered ☐ Driven ☐ Dug ☐ Other

BAILING OR PUMPING TEST
(specify one by circling)

WELL TEST

Test rate 18 gpm Duration of test 1 hrs.

Drawdown (water level during pumping) 15 ft.

Measured from: ☒ top of casing ☐ ground level ☐ Other

Static Level (depth to water) 55 ft. Date: 2/28/89

Quality (clear, cloudy, taste, odor) clear

PUMP

Type of pump submersible Capacity 10 gpm

Pump set at 105' ft.

Pump installed by Adams & Sons

Pitless Device ☒ Adapter ☐ Preassembled unit

Use of Well single family dwelling

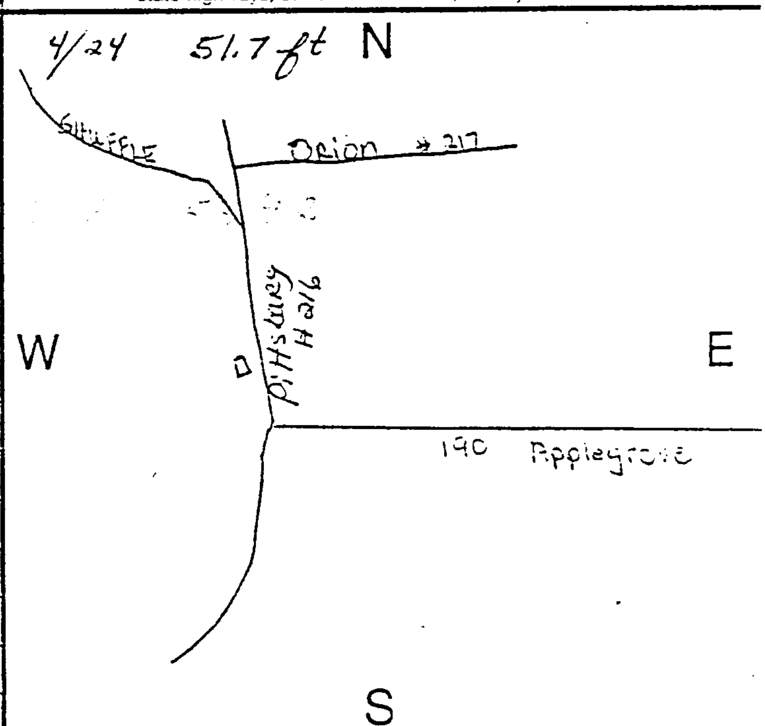
elevation - 1105 ft

WELL LOG*

Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand	From	To
sand, gravel, clay	0 ft.	45 ft.
sandyshale	45	60
sandstone	60	105
sandyshale	105	108
sandstone	108	135
sandyshale	135	145

SKETCH SHOWING LOCATION

Show distances well lies from numbered state highways, street intersections, county roads, etc.



*If additional space is needed to complete well log, use next consecutively numbered form.

DNR 7802.88

LLING FIRM Adams & Sons SIGNED Debbi Adams

DDRESS 1174 Mt. Pleasant NW DATE 2/28/89

ITY, STATE, ZIP N.Canton, OH 44720 ODH REGISTRATION NUMBER 395

Completion of this form is required by 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.

bedrock (LOCATED)
CMS #41
old number

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Columbus, Ohio

(65)
No. 104473
B CMS-15

County Stark Township Plain Section of Township or Lot Number Pitt. Rd.

Owner Mont Ford W. Kepler Address RFD 7 N. Canton

7439
Location of property 7 Mile North of N Canton Canal Fulton Rd. on Pittsburgh Road.

CONSTRUCTION DETAILS

Casing diameter 4 Length of casing 53'-6"

Type of screen None Length of screen

Type of pump Not set yet

Capacity of pump

Depth of pump setting

PUMPING TEST

With 4" Baler

Pumping rate 10+ G.P.M. Duration of test 1/2 hrs

Drawdown None ft. Date June 27 19

Developed capacity 600 Gph

Static level—depth to water 27' ft

Pump installed by

elevation - 1105 ft

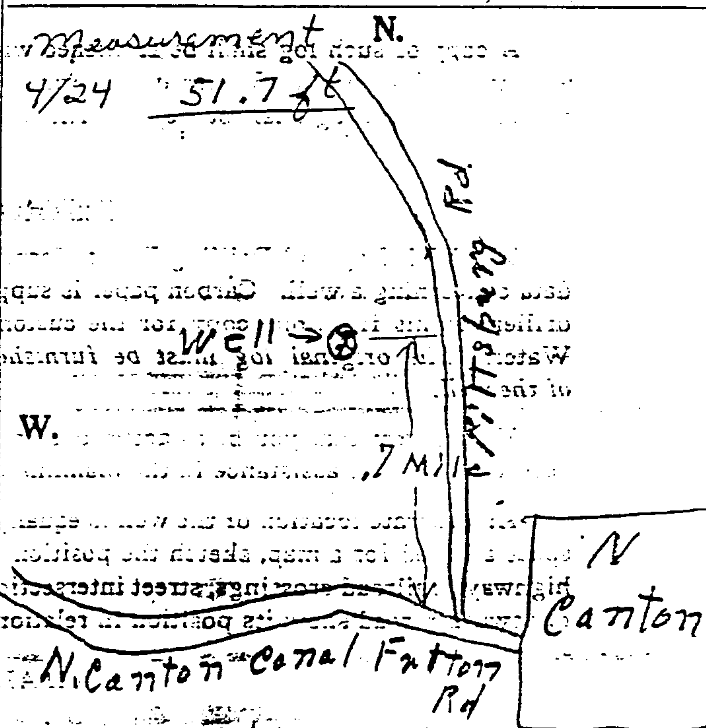
WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
clay Sand & Gravel	0 Feet	20 Ft.
y mud & Gravel	20'	42'
reak of Gravel with		
me water	42'	47'
hite clay	47	53
nd rock	53'	60
t water at		
7' in Sand Rock		

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

Measurement
4/24 51.7 ft



New Well drilled → March 1989

Driller Adams + Son
499-8424

S. (51.7 ft 4/24

See reverse side for instructions

Drilling Firm Glenn S. Ripley Date June 28, 1953

Address Canal Fulton, Ohio Signed Glenn S. Ripley

bedrock

WELL LOG AND DRILLING REPORT

CMS - B 17

491182

ORIGINAL

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Geological Survey
Fountain Square
Columbus, Ohio 43224 Phone (614) 466-5344

COUNTY Stark TOWNSHIP Plain SECTION OF TOWNSHIP OR LOT NUMBER 6

OWNER Hermann Heid ADDRESS 3472 Orion Rd. N.W. ~~N. Canton, Ohio 44720~~

LOCATION OF PROPERTY same

CONSTRUCTION DETAILS

Casing diameter 5 5/8" Length of casing 50'

Type of screen --- Length of screen

Type of pump submersible

Capacity of pump

Depth of pump setting 50'

Date of completion 10-21-77

BAILING OR PUMPING TEST

(specify one by circling)

Test rate 20 gpm Duration of test 2 hrs

Drawdown 11 ft Date 10-21-77

Static level (depth to water) 19 ft

Quality (clear, cloudy, taste, odor) clear; oderless; 20 grains hard; 8 pH; 0.1 ppm iron

Pump installed by Paul D. Brogan

elevation – 1166 ft.

WELL LOG*

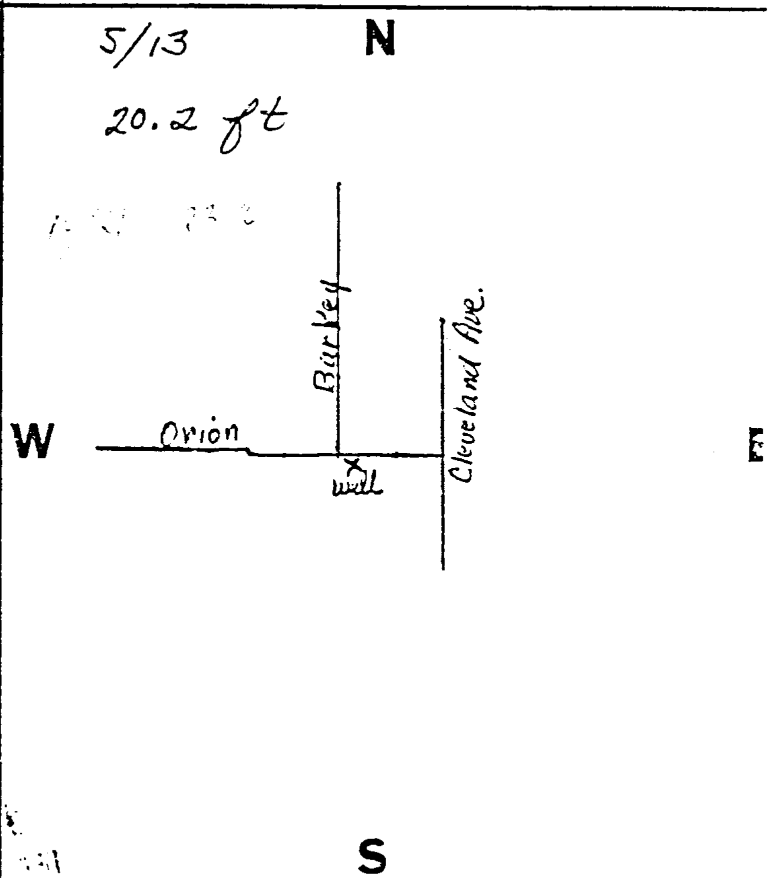
Formations: sandstone, shale, limestone, gravel, clay	From	To
Sand, gravel & boulders	0 ft	18 ft
Sand	18'	24'
Blue clay	24'	28'
Coal	28'	34'
Fireclay	34'	36'
Blue shale	36'	48'
Sandstone	48'	54'
Shale	54'	100'

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.

5/13

20.2 ft



DRILLING FIRM Paul D. Brogan 7103 Columbus Rd. N.E.

ADDRESS Louisville, Ohio 44641

DATE October 21, 1977

SIGNED Paul D Brogan

*If additional space is needed to complete well log, use next consecutive numbered form.

Bedrock

NO CARBON PAPER
NECESSARY
SELF-TRANSCRIBING

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

CMS - 18
B 595994

COUNTY STARK TOWNSHIP PLAIN SECTION OF TOWNSHIP UNIONTOWN
OWNER OAKCREST Homes ADDRESS 12755 CLEVELAND
LOCATION OF PROPERTY 3557 - 59 MT. PLEASANT

CONSTRUCTION DETAILS

Casing diameter 4" Length of casing 104'
Type of screen ______ Length of screen ______
Type of pump ______
Capacity of pump ______
Depth of pump setting ______
Date of completion ______

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 14 gpm Duration of test ______ hr
Drawdown 60 ft Date 5-15-81
Static level (depth to water) 80
Quality (clear, cloudy, taste, odor) ______
elevation - 1186 ft.
Pump installed by ______

WELL LOG*

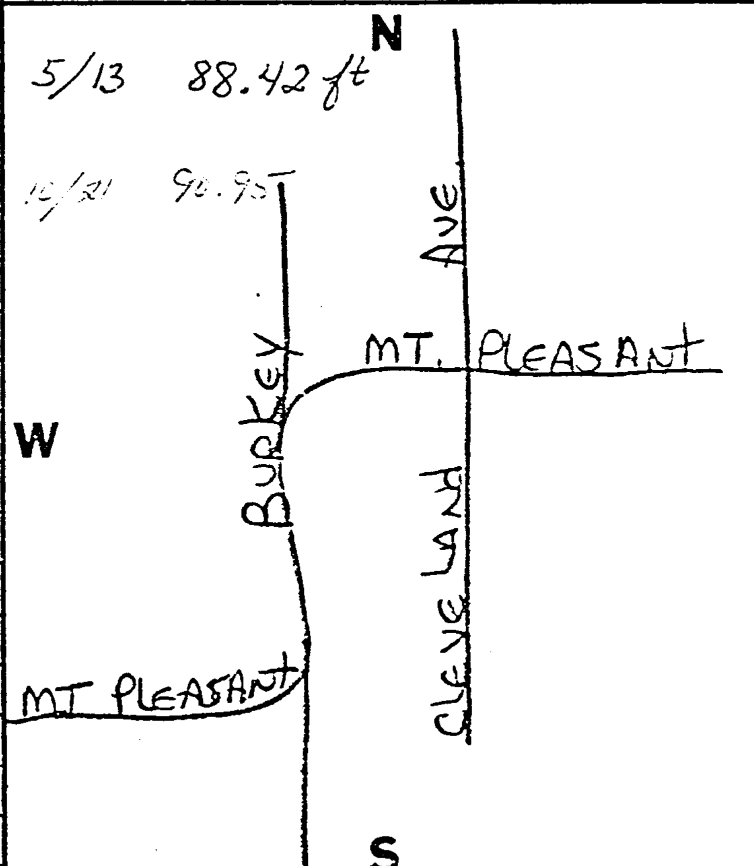
Formations: sandstone, shale, limestone, gravel, clay	From	To
SAND & CLAY	0 ft	32 ft
LIMESTONE	32	33
SHALE ROCK	33	92
LIMESTONE	92	93
SHALE ROCK	93	152
SAND ROCK	152	165

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.

5/13 88.42 ft

10/21 90.95



DRILLING FIRM Cooper's Well Drilling DATE 5-15-81
ADDRESS 2206 Killian Rd Akron SIGNED Carl Cooper

*If additional space is needed to complete well log, use next consecutive numbered form.

ORIGINAL COPY - ODNR, DIVISION OF WATER, FOUNTAIN SQ., COLS., OHIO 43224

* bedrock

WELL LOG AND DRILLING REPORT

670578

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

NO CARBON PAPER NECESSARY- SELF-TRANSCRIBING

get blue house

B CMS-19

Permit Number

COUNTY Stark TOWNSHIP Plain SECTION OF TOWNSHIP 6

OWNER Jeff Wines ADDRESS 3950 Mt. Pleasant NW, Canton, OH 4472

LOCATION OF PROPERTY same

CONSTRUCTION DETAILS

Casing diameter 5" Length of casing 87'

Type of screen Length of screen

Type of pump

Capacity of pump

Depth of pump setting

Date of completion
Rotary ☐ or Cable ☐

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 20 gpm Duration of test 3 h

Drawdown none ft Date 10/7/87

Static level (depth to water) 40

Quality (clear, cloudy, taste, odor) clear

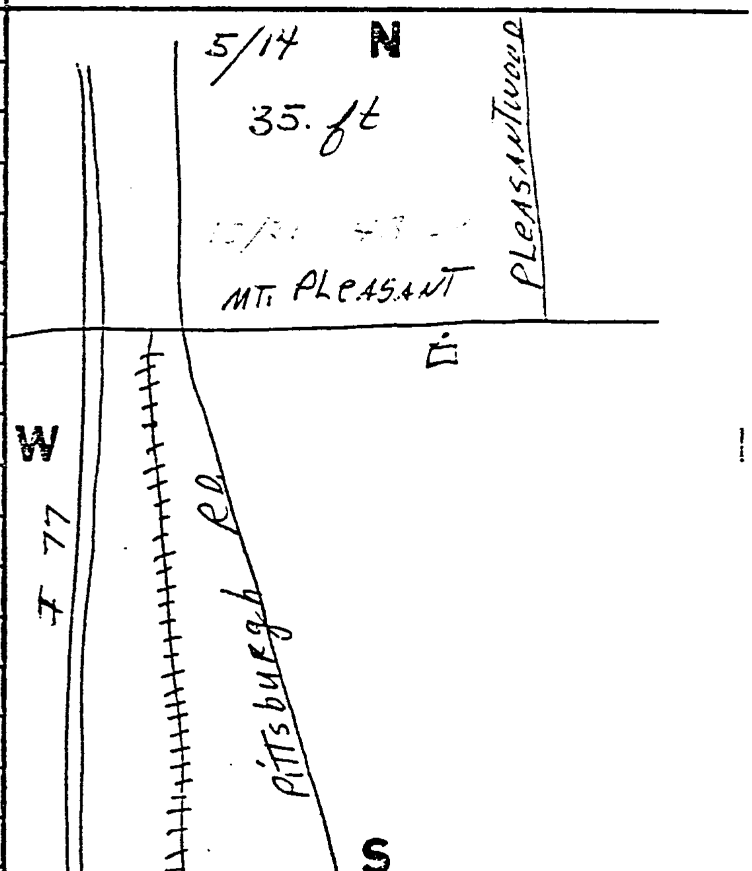
Pump installed by elevation - 1125 ft

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
drift	0 ft	10 ft
sand, gravel, clay	10	30
sand, gravel	30	65
sandy shale	65	77
limestone	77	79
sand, gravel, clay	79	84
sandstone	84	100
shale	100	103
sandstone	103	110

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.



* If additional space is needed to complete well log, use next consecutively numbered form.

DNR 780

DRILLING FIRM ADAMS & SONS ~~Well Drilling, Inc.~~ REGISTRATION NUMBER 395 DATE 10/8/87

ADDRESS 4310 - 38th St., N.W. ~~492-0150 Canton, Ohio 44718~~ SIGNED D Adams

Completion of this form is required by 1521.05, Ohio Revised Code - file within 30 days after completion.

WHITE ORIGINAL COPY - ODNR, DIVISION OF WATER, FOUNTAIN SQ., COLS., OHIO 43224 / Blue - Customer's Copy / Pink - Driller's Copy / Green - Local Health Dept. Copy

County Permit No. ____

WELL LOG AND DRILLING REPORT

CMS- 21 ORIGINAL

B 550961

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

Carol Kline daughter in Dublin

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP ____

OWNER V. S. F. construction ADDRESS ____

LOCATION OF PROPERTY 4665 Shuffel Road

CONSTRUCTION DETAILS

sing diameter 5" Length of casing 40'

pe of screen ____ Length of screen ____

pe of pump ____

pacity of pump ____

pth of pump setting ____

te of completion ____

BAILING OR PUMPING TEST

(specify one by circling)

Test rate 18 gpm Duration of test 1 hrs

Drawdown 5 ft Date 6-8-79

Static level (depth to water) 20 ft

Quality (clear, cloudy, taste, odor) no odor

elevation - 1099 ft

Pump installed by ____

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
sand-gravel	0 ft	30 ft
Gray shale	30	60
Gray sandstone	60	80

SKETCH SHOWING LOCATION

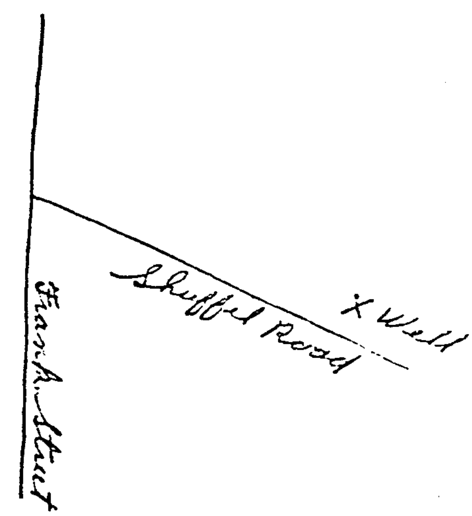
Locate in reference to numbered state highways, street intersections, county roads, etc.

5/13

17.7 ft

N

W



E

S

DRILLING FIRM John E. Smith DATE June 8-1979

ADDRESS 1025 Swigart Road
Barberton Ohio 44203

SIGNED John E. Smith

*If additional space is needed to complete well log, use next consecutive numbered form.

676104

WELL LOG AND DRILLING REPORT

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

NO CARBON PAPER NECESSARY—SELF-TRANSCRIBING

B CMS - 22
4/24 17.9 ft

Permit Number

COUNTY STARK TOWNSHIP JACKSON SECTION OF TOWNSHIP

OWNER LIQUID CONTROL CORP. ADDRESS 7576 FREEDOM AVE.

LOCATION OF PROPERTY NORTH CANTON INDUSTIAL PARK

CONSTRUCTION DETAILS

Casing diameter 7" Length of casing 47½'

Type of screen — Length of screen SHOE

Type of pump 1½ HP SUB

Capacity of pump 25 GPM

Depth of pump setting 85'

Date of completion 4-26-88

Rotary ☐ or Cable ☒

BAILING OR PUMPING TEST

(specify one by circling)

Test rate 40 gpm Duration of test 2 hr

Drawdown 18' ft Date 4-26-88

Static level (depth to water) 22'

Quality (clear, cloudy, taste, odor) 1862 HARD

PH. 8 5 PPM IRON

Pump installed by FEARON + FELLER

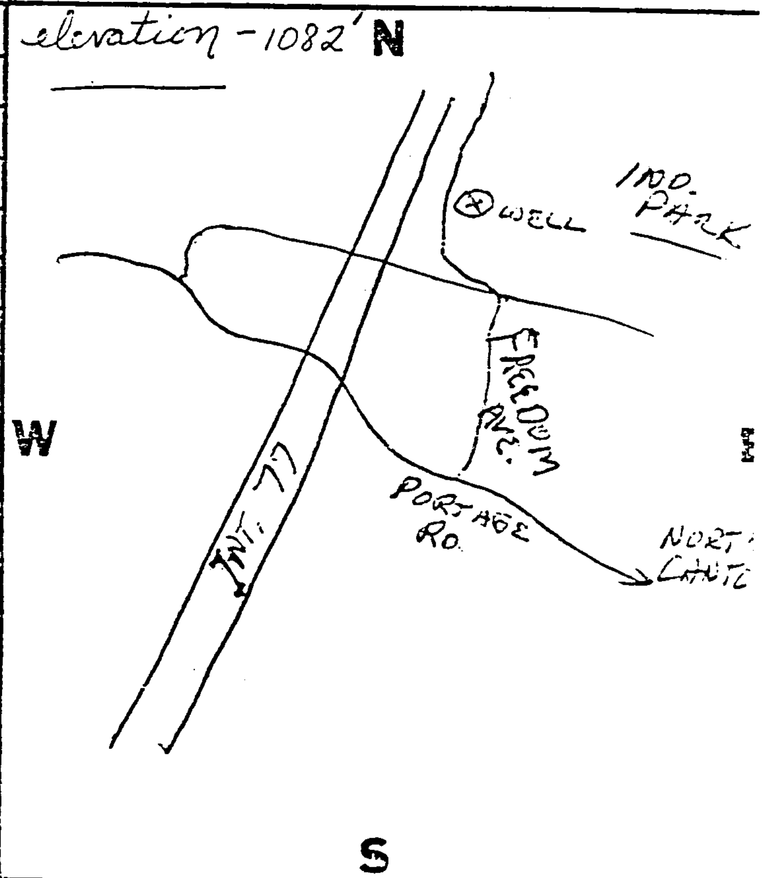
WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
BROWN CLAY	0 ft	5 ft
WASH-SAND-GRAVEL	5	44
SANDY SHALE (W)	44	80'
GREY SHALE -	80	105
COAL + CLAY	105	112
GREY SANDY SHALE (W)	112	155

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.

elevation - 1082'



* If additional space is needed to complete well log, use next consecutively numbered form.

CNR 7802

DRILLING FIRM FEARON + FELLER INC REGISTRATION NUMBER 50 DATE 4-26-88

ADDRESS RT 1 BEACH CITY, OH SIGNED Wm. J. Feller

Completion of this form is required by 1521.05 Ohio Revised Code - file within 30 days after completion.

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Bedrock

WELL LOG AND DRILLING REPORT

ORIGINA

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus, Ohio 43212

PLEASE USE PENCIL OR TYPEWRITER
DO NOT USE INK.

Nº 330745

B CMS-23

County Stark Township [illegible] Section of Township

Owner C. M. McBride Address 4071 Strasser St., N. Canton, Ohio

Location of property Off of Strasser Rd., N. Canton

CONSTRUCTION DETAILS

Casing diameter $6\frac{1}{2}$" Length of casing 57'

Type of screen None Length of screen

Type of pump 3/4 HP [illegible]

Capacity of pump [illegible]

Depth of pump setting [illegible]

Date of completion [illegible]

BAILING OR PUMPING TEST

Pumping Rate 45 G.P.M. Duration of test 1 hrs

Drawdown 16 ft. Date Aug. 19, 19

Static level-depth to water 24 ft

Quality (clear, cloudy, taste, odor) clear

15 grains hard 8.0PH 1.5 PPM Iron

Pump installed by

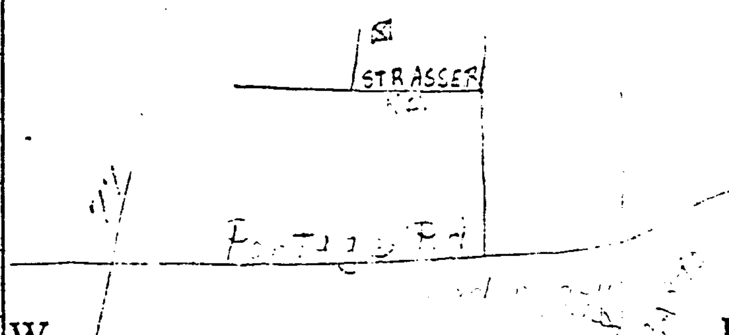
WELL LOG*

Formations Sandstone, shale, limestone, gravel and clay	From	To
rown wash	0 Feet	47 Ft.
Gray plastic shale	47	55
Gray sandy shale in and out	55	71

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.

N.



W. E.

5/31/89
depth to water 28'

Collar Elev: 1090'
− 38'
+1052 ft water level

S.

See reverse side for instructions

Drilling Firm Stockert Drilling Co. Date August 24, 1965

Address R. 1, Strasburg, Ohio Signed [illegible]

*If additional space is needed to complete well log, use next consecutive numbered form

69509 Bedrock

CMS - 24

607015

B

NO CARBON PAPER NECESSARY– SELF-TRANSCRIBING

1/B

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
Fountain Square
Columbus, Ohio 43224

COUNTY Stark TOWNSHIP Jackson SECTION OF TOWNSHIP 12

OWNER Accu-rite Tool & Die Co. ADDRESS 4040 Portage N.W. Canton

LOCATION OF PROPERTY 7295 Sunset Strip N.Canton

CONSTRUCTION DETAILS

Casing diameter 6" Length of casing 33'

Type of screen Length of screen

Type of pump

Capacity of pump

Depth of pump setting

Date of completion

BAILING OR PUMPING TEST
(specify one by circling)

Test rate 15 gpm Duration of test 1 hr

Drawdown 60 ft Date 11/3/81

Static level (depth to water) 14 ft

Quality (clear, cloudy, taste, odor) clear

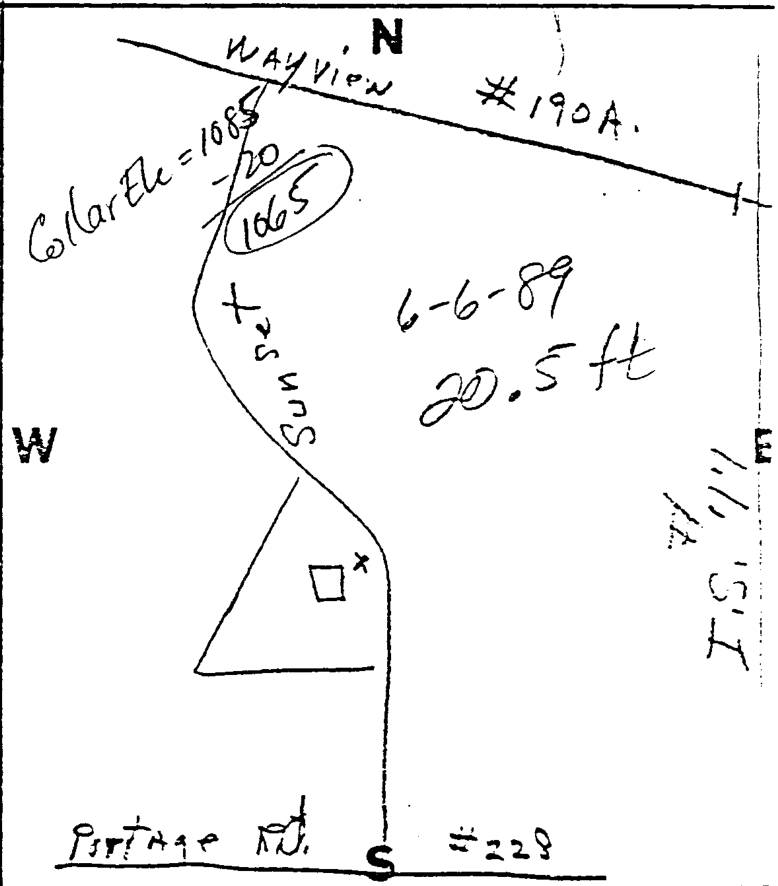
Pump installed by

WELL LOG*

Formations: sandstone, shale, limestone, gravel, clay	From	To
drift	0 ft	33 ft
sandyshale	33	95
shale	95	128

SKETCH SHOWING LOCATION

Locate in reference to numbered state highways, street intersections, county roads, etc.



DRILLING FIRM ADAMS & SONS Well Drilling, Inc. DATE 11/5/81

ADDRESS 4319 - 38th St. N.W. 492-2160 Canton, Ohio 44718 SIGNED John Adams

*If additional space is needed to complete well log, use next consecutive numbered form.

ORIGINAL COPY - ODNR, DIVISION OF WATER, FOUNTAIN SQ., COLS., OHIO 43224

Bedrock

WELL LOG AND DRILLING REPORT

CMS - 25

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING

permit # H.B.

State of Ohio
DEPARTMENT OF NATURAL RESOURCES B
Division of Water
65 S. Front St., Rm. 815 Phone (614) 469-2646
Columbus, Ohio 43215

No. 378130

Northern older Well

County Stark Township Jackson Section of Township 12

Owner Serbian Church (Mr. J. Maxwell) Address 10035 Muckley Dr. SW, Waynesburg, Ohio

Location of property Just off Wayview st, NCanton, Ohio

CONSTRUCTION DETAILS

Casing diameter 6" Length of casing 70'

Type of screen ______ Length of screen ______

Type of pump ______

Capacity of pump ______

Depth of pump setting ______

Date of completion ______

BAILING OR PUMPING TEST

(Specify one by circling)

Test Rate 18 G.P.M. Duration of test 1 hrs

Drawdown 15 ft. Date 5/20/68

Static level-depth to water 35 ft

Quality (clear, cloudy, taste, odor) clear

Pump installed by ______

WELL LOG*

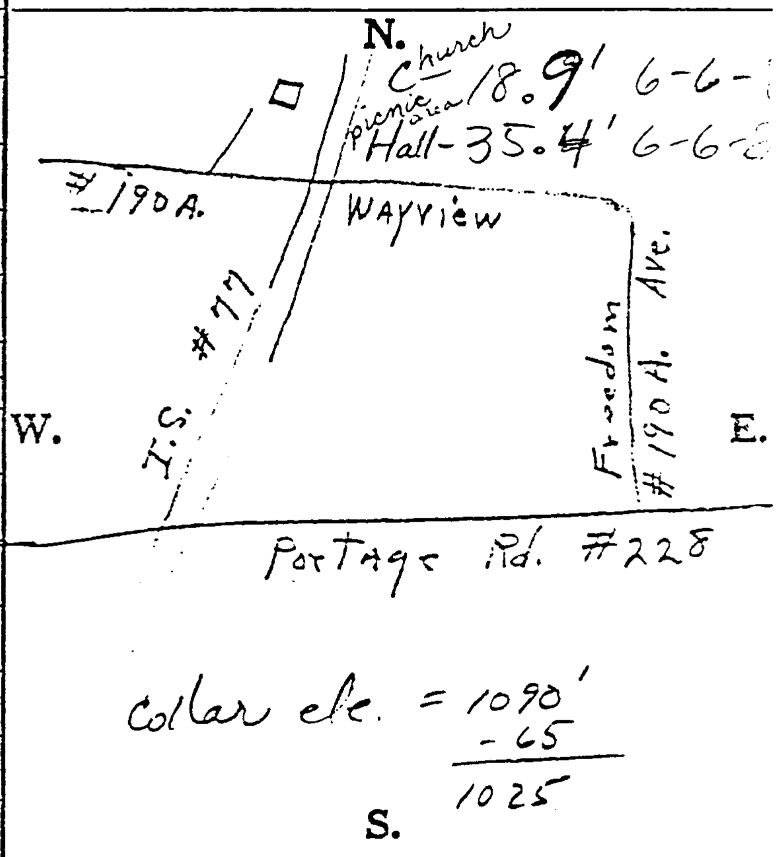
Formations Sandstone, shale, limestone, gravel and clay	From	To
drift	0 Feet	64 Ft.
shale	64	97

Hall Collar = 1102
-35
1067

Church = 1090
-19
1070

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



Drilling Firm ______ Date 5/27/68

Address ______ Signed John Adam

*If additional space is needed to complete well log, use next consecutive numbered form.

Sand + Gravel

WELL LOG AND DRILLING REPORT

PLEASE USE PENCIL OR TYPEWRITER DO NOT USE INK.

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus 12, Ohio

CMS-20 G

No 289936

County STARK Township PLAIN Section of Township 6

Owner A.J. OHERM Address 4032 MT. PLEASENT

Location of property ONE MI. WEST OF RT. 8 ON

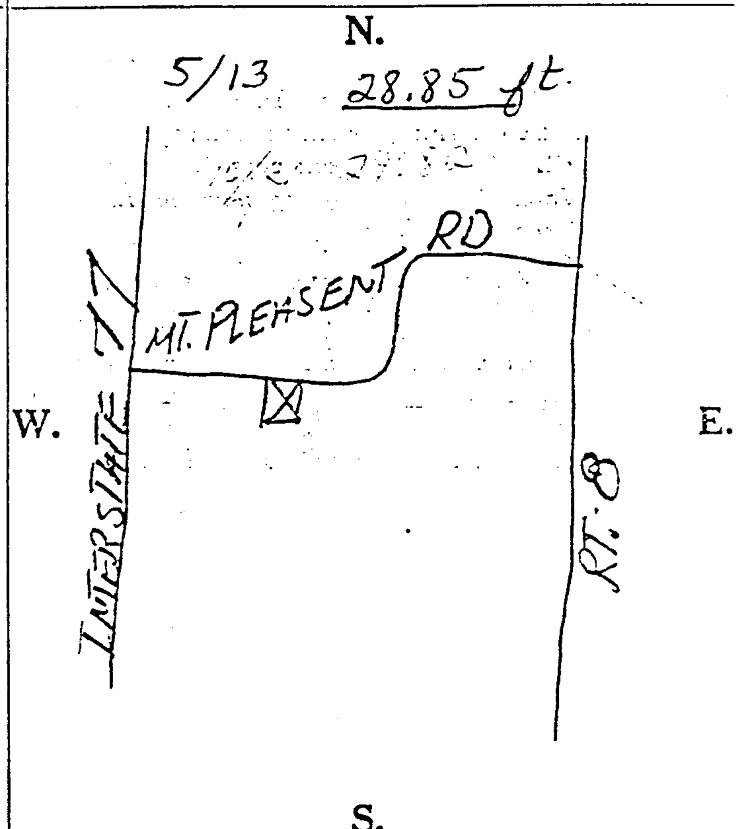
CONSTRUCTION DETAILS	BAILING OR PUMPING TEST
Casing diameter 4" Length of casing 70'	Pumping Rate 20 G.P.M. Duration of test 2 hrs.
Type of screen Length of screen	Drawdown 5 ft. Date 7-16-68
Type of pump	Static level-depth to water 27 ft.
Capacity of pump	Quality (clear, cloudy, taste, odor)
Depth of pump setting	elevation - 1115 ft.
Date of completion	Pump installed by

WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
	0 Feet	29 Ft.
CLAY + SAND		
SAND + GRAVEL	29	70
WATER AT 70'		

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



See reverse side for instructions

Drilling Firm M.R. VENOSDLE Date 7-16-68

Address 2513-44 ST. N.W. CANTON OHIO Signed Melvin R. Venosdle

WELL LOG AND DRILLING REPORT

ORIGINAL

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
1562 W. First Avenue
Columbus 12, Ohio

B

PLEASE USE PENCIL
OR TYPEWRITER
DO NOT USE INK.

No. 283266

CMS - 26

County: Stark   Township: Jackson   Section of Township: 13

Owner: Fred Dohler   Address: 5820 Dressler N.W., No. Canton

Location of property: Same

CONSTRUCTION DETAILS	BAILING ~~OR PUMPING~~ TEST
Casing diameter 4" Length of casing 88'	Pumping Rate 15 G.P.M. Duration of test ..... hrs.
Type of screen ...... Length of screen	Drawdown — ft. Date 9-6-62
Type of pump	Static level-depth to water 20 ft.
Capacity of pump	Quality (clear, cloudy, taste, odor) Clear
Depth of pump setting	
Date of completion	Pump installed by ......

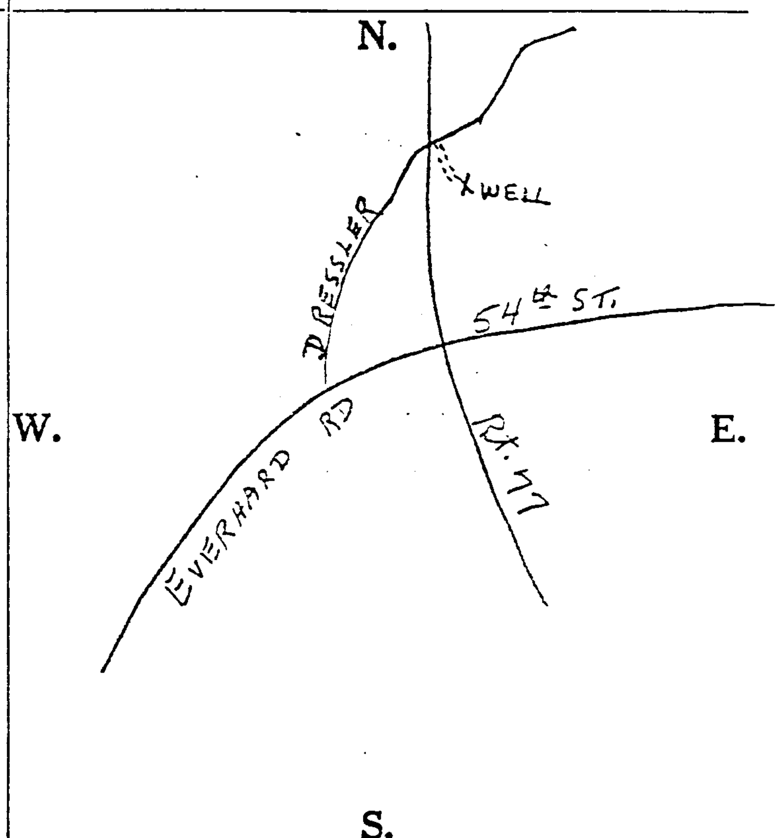
WELL LOG

Formations Sandstone, shale, limestone, gravel and clay	From	To
Muddy gravel	0 Feet	78 Ft.
Soft sandrock	78'	82'
Stiff mud	82'	87'
Gray Sandrock	87'	96'

Water at 88'-96'

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



See reverse side for instructions

Drilling Firm: Evereet Waltz & Co., Inc.   Date: 2-28-63

Address: Strasburg, Ohio   Signed: A. D. Carr

WELL LOG AND DRILLING REPORT

ORIGINAL

B CMS- 27

No. 374593

NO CARBON PAPER NECESSARY— SELF-TRANSCRIBING H.B.

permit #15535

State of Ohio
DEPARTMENT OF NATURAL RESOURCES
Division of Water
65 S. Front St., Rm. 815 Phone (614) 469-2646
Columbus, Ohio 43215

County Stark Township Plain Section of Township 19

Owner Phil Wagler (Roman Wagler cont.) Address 12401 Market Ave.NW,Hartville, Ohio

Location of property 3095 Berenwood NW,Canton,O

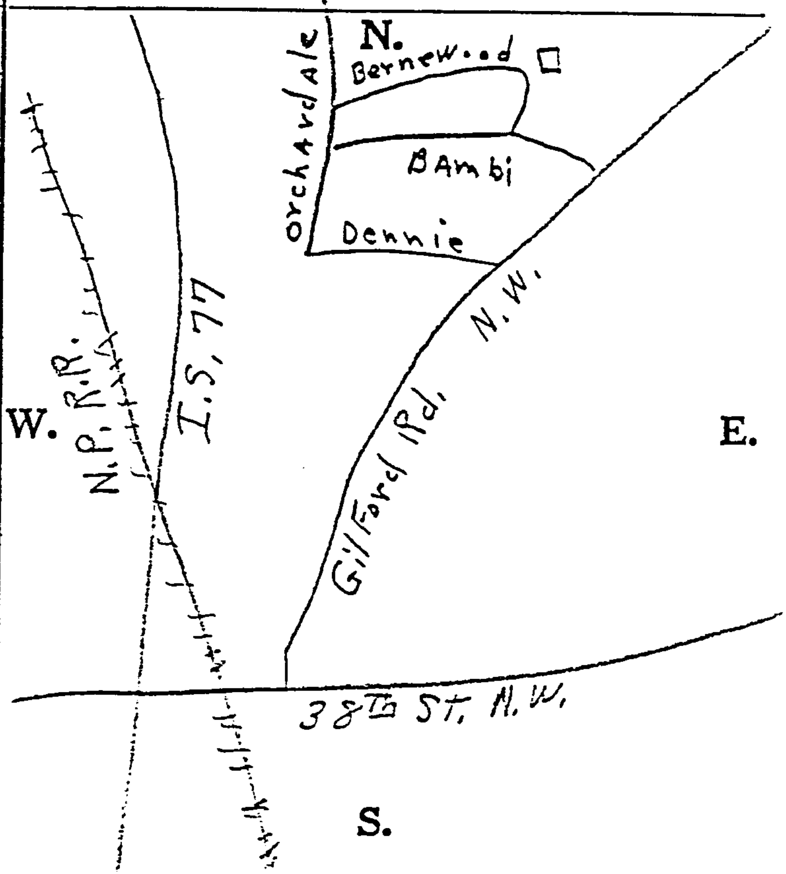
CONSTRUCTION DETAILS		BAILING OR PUMPING TEST (Specify one by circling)	
Casing diameter 4"	Length of casing 188'	Test Rate 10 G.P.M.	Duration of test 2 hrs.
Type of screen	Length of screen	Drawdown 10 ft.	Date 3/22/68
Type of pump		Static level-depth to water 40 ft.	
Capacity of pump		Quality (clear, cloudy, taste, odor) clear	
Depth of pump setting			
Date of completion		Pump installed by	

WELL LOG*

Formations Sandstone, shale, limestone, gravel and clay	From	To
rift	0 Feet	181 Ft.
roken sandrock	181	190

SKETCH SHOWING LOCATION

Locate in reference to numbered State Highways, St. Intersections, County roads, etc.



rilling Firm

Address

Date 4/10/68

Signed

*If additional space is needed to complete well log...

APPENDIX C

```
C   ************************************************************
C
C                  PROGRAM TO COMPUTE CAPTURE-ZONE AREAS
C
C                  WRITTEN BY E.S. BAIR and C.M. SAFREED
C
C   ************************************************************
C
      REAL  V11, V12, V21, V22, AREA, AREA1, AREAB, LENGTH, ASEG,
     +      ASEG1, ASEG2, SF, WIDTH, EPX(36), EPY(36), CENTER(2),
     +      XMAX, XMIN, YMAX, YMIN, AREA2, SUM, XCENTER, YCENTER,
     +      XC, YC, HWIDTH, HLENGTH
      INTEGER  COUNT
      DATA  NP/36/
      CHARACTER*14  NAME
      OPEN (UNIT=8,FILE='B:AREA.OUT',STATUS='NEW')
C
C  READ FILENAME & WRITE TO AREA.OUT FILE
C
      WRITE (*,100)
  100 FORMAT (5X,'PATH:FILENAME (Run #.Well #):  ')
      READ (*,105) NAME
  105 FORMAT (A14)
      WRITE (8,106) NAME
  106 FORMAT (/10X,'PATH:FILENAME:  ',A14)
C
C  READ IN X & Y COORDINATES OF WELL
C
      WRITE (*,121)
  121 FORMAT (10X,'X-COORDINATE OF WELL (ft): ')
      READ (*,119) CENTER(1)
  119 FORMAT (F8.0)
      WRITE (8,122) CENTER(1)
  122 FORMAT (/10X,'X-WELL (ft): ',F8.0)
      WRITE (*,123)
  123 FORMAT (10X,'Y-COORDINATE OF WELL (ft): ')
      READ (*,125) CENTER(2)
  125 FORMAT (F8.0)
      WRITE (8,124) CENTER(2)
  124 FORMAT (10X,'Y-WELL (ft): ',F8.0//)
C
C  READ ARRAY OF ENDPOINT VALUES FROM GWPATH v 4.0 OUTPUT FILE
C                                and
C               ECHO ARRAY VALUES TO AREA.OUT FILE
C
      WRITE (8,127)
  127 FORMAT (1X,'X & Y COORDINATES OF ENDPOINTS (ft)',/)
C
      OPEN (UNIT=9,FILE=NAME,STATUS='OLD')
C
```

```
      DO 10 I=1,NP
            READ (9,130) EPX(I),EPY(I)
            WRITE (8,130) EPX(I),EPY(I)
  130       FORMAT (2F12.2)
   10       CONTINUE
C
C  INITIALIZE INVERTED VALUES OF X & Y IN GRID
C
      XMAX=0.
      YMAX=0.
      XMIN=15000.
      YMIN=21000.
C
C  COMPUTE RANGE OF ENDPOINT VALUES
C
      DO 15 I=1,NP
            IF (EPX(I).GT.XMAX) XMAX=EPX(I)
            IF (EPX(I).LT.XMIN) XMIN=EPX(I)
            IF (EPY(I).GT.YMAX) YMAX=EPY(I)
            IF (EPY(I).LT.YMIN) YMIN=EPY(I)
   15       CONTINUE
C
C  COMPUTE APPARENT LENGTH, WIDTH AND SHAPE FACTOR OF CAPTURE ZONE
C
      WIDTH=XMAX-XMIN
      LENGTH=YMAX-YMIN
      SF=LENGTH/WIDTH
C
C  COMPUTE RELATIVE CENTROID OF CAPTURE ZONE
C
      HWIDTH=WIDTH/2.
      HLENGTH=LENGTH/2.
      XC=XMIN+HWIDTH
      YC=YMIN+HLENGTH
      XCENTER=XC-CENTER(1)
      YCENTER=YC-CENTER(2)
C
C  INITIALIZE SEGMENT AREA AND COUNTER TO ZERO
C
      SUM=0.
      COUNT=0
C
C  COMPUTE LENGTH OF DISTANCE VECTORS & AREAS OF TRIANGULAR SEGMENTS
C                                 and
C                        WRITE VALUES TO AREA.OUT FILE
C
      WRITE (8,131)
  131 FORMAT (//10X,'COMPUTED AREAS OF TRIANGULAR SEGMENTS (sq ft)',/)
C
```

```
      DO 30 I=1,NP-1
            V11=EPX(I)-CENTER(1)
            V12=EPY(I)-CENTER(2)
            V21=EPX(I+1)-CENTER(1)
            V22=EPY(I+1)-CENTER(2)
            ASEG1=ABS((V11*V22)-(V12*V21))
            ASEG=0.5*ASEG1
            AREA1=SUM+ASEG
            SUM=AREA1
            COUNT=COUNT+1
            WRITE (8,135) COUNT,ASEG,AREA1
  135 FORMAT('SEG NO: ',I2,5X,'SEG AREA: ',F10.0,5X,'CUM AREA: ',F12.0)
   30       CONTINUE
C
C  COMPUTE AREA OF LAST SEGMENT TO CLOSE POLYGON
C
      V11=EPX(NP)-CENTER(1)
      V12=EPY(NP)-CENTER(2)
      V21=EPX(1)-CENTER(1)
      V22=EPY(1)-CENTER(2)
      ASEG2=ABS((V11*V22)-(V12*V21))
      AREA2=0.5*ASEG2
C
C  COMPUTE AREA OF CAPTURE ZONE
C
      AREA=AREA1+AREA2
      AREAB=AREA/43560.
C
C  WRITE VALUE TO AREA.OUT FILE
C
      WRITE (8,137) NP,AREA2,AREA
  137 FORMAT('SEG NO: ',I2,5X,'SEG AREA: ',F10.0,5X,'CUM AREA: ',F12.0)
C
C  WRITE SUMMARY RESULTS TO AREA.OUT FILE
C
      WRITE (8,235)
  235 FORMAT (///'<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<RESULTS>>>>>>>>>>>>
     +>>>>>>>>>>>>>>>>>>>>>>')
      WRITE (8,140) NAME
  140 FORMAT (//5X,'PATH:FILENAME (Run #.Well #):  ',A14)
      WRITE (8,145) AREA
  145 FORMAT (/5X,'CAPTURE-ZONE AREA (sq ft): ',F11.0)
      WRITE (8,150) AREAB
  150 FORMAT (23X,'(acres):        ',F6.1)
      WRITE (8,149)
  149 FORMAT (//20X,'----- CAPTURE-ZONE STATISTICS (ft) -----')
      WRITE (8,151) SF
  151 FORMAT (/31X,'SHAPE FACTOR: ',F5.2)
      WRITE (8,103) HWIDTH,XMIN,CENTER(1),XCENTER
```

```
  103 FORMAT (/' HALF-WIDTH: ',F6.0,3X,'X-MIN: ',F6.0,3X,
     +  'X-WELL: ',F6.0,3X,'X-CENTROID: ',F5.0)
      WRITE (8,104) HLENGTH,YMIN,CENTER(2),YCENTER
  104 FORMAT ('HALF-LENGTH: ',F6.0,3X,'Y-MIN: ',F6.0,3X,
     +  'Y-WELL: ',F6.0,3X,'Y-CENTROID: ',F5.0//)
      WRITE (8,260)
  260 FORMAT ('<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<>>>>>>>>>>>>>>>>>>
     +>>>>>>>>>>>>>>>>>>')
C
C  DISPLAY RESULTS TO CRT
C
      WRITE (*,235)
      WRITE (*,240) NAME
  240 FORMAT (///5X,'PATH:FILENAME (Run #.Well #):  ',A14)
      WRITE (*,245) AREA
  245 FORMAT (//10X,'CAPTURE-ZONE AREA (sq ft): ',F11.0)
      WRITE (*,250) AREAB
  250 FORMAT (28X,'(acres):        ',F6.1)
      WRITE (*,259) LENGTH
  259 FORMAT (//10X,'CAPTURE-ZONE LENGTH (ft): ',F8.0)
      WRITE (*,251) WIDTH
  251 FORMAT (24X,'WIDTH (ft): ',F8.0)
      WRITE (*,255) SF
  255 FORMAT(16X,'SHAPE FACTOR (L/W): ',5X,F5.2)
      WRITE (*,261)
  261 FORMAT (//10X,'RECTANGULAR-CENTROID COORDINATES OF CAPTURE ZONE --
     +')
      WRITE (*,263) XCENTER
  263 FORMAT (49X,'X-CENTER (ft): ',F6.0)
      WRITE (*,264) YCENTER
  264 FORMAT (49X,'Y-CENTER (ft): ',F6.0///)
      WRITE (*,260)
      STOP
      END
```